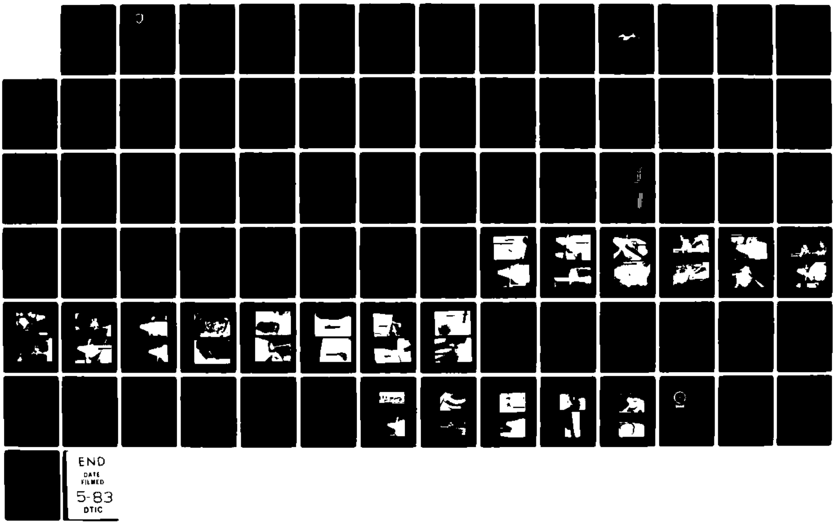
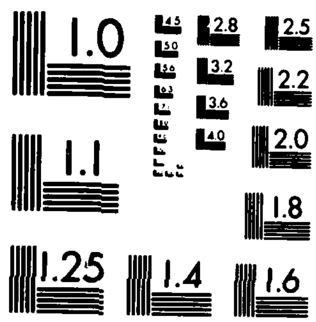
AD-A127 191 LIMITED ARTIFICIAL AND NATURAL ICING TEST OF THE OV-1D (RE-EVALUATION)(U) ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB CA R B CARPENTER ET AL. JUN 82 1/1

UNCLASSIFIED USAAEFA-81-21 F/G 8/12 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

(12)

AD A127191

USAAEFA PROJECT NO. 81-21

MITED ARTIFICIAL AND NATURAL ICING TEST OF THE OV-1D (RE-EVALUATION)

FINAL REPORT

BY

RONALD B. CARPENTER
MAJ, AR
PHASE I PROJECT OFFICER/PROJECT PILOT

ROBERT N. WARD
LTC, TC
PHASE II PROJECT OFFICER/PROJECT PILOT

ROBERT D. ROBBINS
PHASE III PROJECT OFFICER/PROJECT PILOT

JUNE 1982

UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

DISCLAIMER NOTICE

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

TRADE NAMES

The use of trade names in this report does not constitute an official endorsement or approval of the use of the commercial hardware and software.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USAAEFA PROJECT NO. 81-21	2. GOVT ACCESSION NO.: AD-A127191
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): LIMITED ARTIFICIAL AND NATURAL ICING TEST OF THE OV-1D	5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT 1 FEB - 3 MAY 1982
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): RONALD B. CARPENTER, ROBERT N. WARD, ROBERT D. ROBBINS	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US ARMY AVN ENGINEERING FLIGHT ACTIVITY, EDWARDS AIR FORCE BASE, CA 93523	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: EN82Y0233 (Order No. MEC2061)
11. CONTROLLING OFFICE NAME AND ADDRESS: US ARMY AVN RESEARCH & DEVELOPMENT COMMAND, 4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120	12. REPORT DATE: JUNE 1982
	13. NUMBER OF PAGES: 84
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

- Aircraft Performance
- Engine Inlets
- Icing Evaluation
- Ice Protection System Modifications Kits
- OV-1D
- Windshield Anti-Ice

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The USAAEFA conducted an icing evaluation of the engine inlets of an OV-1D aircraft from 1 February through 3 May 1982. The test included artificial icing flights in St. Paul, Minnesota and natural icing flights in Salem, Oregon. A total of 13 test flights, 8 artificial tests and 5 natural tests, totalling 22.8 hours were performed. Total cloud immersion time was 4.2 hours hours for artificial icing and 6.5 for natural icing. A range of temperatures, liquid water contents and droplet sizes were experienced.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The engine inlet ice protection system was modified three times. The modifications included increased electrical power available, increased duty times of heating elements, and addition of insulation in the cowling. The No. 2 engine final configuration cowling produced the most favorable ice accretion characteristics. However, in all cases, ice formed on the propeller blades, propeller spinners and propeller spinner afterbody. In artificial icing tests, ice was found inside the engine inlet. Aircraft performance was significantly degraded apparently due to ice accretion on the propeller blades. Two deficiencies were identified: the inability of the windshield anti-ice system to clear the windshield of ice; and, significant quantities of ice forming on the propeller spinner afterbody. Seven shortcomings were identified. Several procedural recommendations for operating OV-1D aircraft in icing conditions are presented.

DEPARTMENT OF THE ARMY
HQ, US ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120

DRDAV-D

SUBJECT: Directorate for Development and Qualification Position on the Final Report of USAAEFA Project No. 81-21, Limited Artificial and Natural Icing Tests of the OV-1D (Re-Evaluation)

SEE DISTRIBUTION

1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report. The report documents the ice accretion characteristics of the OV-1D aircraft modified to improve the deicing capability of the engine inlet. Results indicate that although some improvement over the basic aircraft ice protection system was obtained, ice continues to form on the engine cowling joints where it could break off and cause engine damage. The standard aircraft windshield ice protection system still fails to maintain a clear windshield to provide effective forward visibility.

2. This Directorate agrees with the report conclusions and the following additional comments are provided. Comments are directed to the report paragraph number.

a. Paragraph 36a. The Phase I and II modified engine nose cowling resulted in improved ice accretion characteristics, but ice still forms which may cause engine damage. In Phase I artificial icing tests, the largest accretions formed on the cowling half joints and struts at -20°C and LWC of .48 gm/m^3. In Phase II artificial icing tests, in moderate levels of intensity, ice continued to form on the cowling half joints and struts with somewhat larger accretions at the colder temperatures.

b. Paragraph 36b. The No. 2 engine cowling assembly Phase III changes exhibited the best ice accretion characteristics of all the configurations tested. Because the engine cowling half joints and struts had been problem areas, Phase III modified the No. 2 engine cowling to provide increased element heating to the cowling half joints and struts. With the exception of one ferry flight, all Phase III testing was in the natural environment, in light icing conditions. Under these conditions the No. 2 engine cowling remained clear of ice, the No. 1 engine cowling did not.

c. Paragraph 36c. Based on the performance increase observed after a propeller ice shed, it is believed that a propeller system with an anti-ice capability would result in significant performance improvements when operating

DRDAV-D
SUBJECT: Directorate for Development and Qualification Position of the Final Report of USAAEFA Project No. 81-21, Limited Artificial and Natural Icing Tests of the OV-1D (Re-Evaluation)

in an icing environment. A propeller anti-ice system, one that would continuously keep the propeller free of ice, would eliminate the need for shedding. Although propeller efficiency would increase, overall aircraft performance would be reduced by the additional electrical power required to operate the anti-ice system.

d. Paragraph 37a. Ice accretion on the propeller spinner afterbody may be ingested through the engine inlet possibly resulting in engine damage. The aircraft propeller spinner afterbody is unheated and accretes ice even at relatively low angles of attack. Ice shed from this area can be ingested and cause engine damage.

e. Paragraph 37b. Failure of the windshield ice protection system to clear the windshield sufficiently to provide an adequate forward field of view after encountering icing conditions. The aircraft's alcohol system is deficient in both ability as well as volume to maintain a clear windshield even in light icing encounters. The aircraft's windshield defog system, when coupled with the alcohol system, was also ineffective. Any improved system should consider a windshield anti-ice system to maintain constant visibility.

f. Paragraph 38a. The ice accretion characteristics of the Phase I engine nose cowling may result in engine damage. In the Phase I modification, the duty cycle of certain heating elements within the engine cowling were increased above that of the standard aircraft. In artificial icing tests, ice continued to accrete on the cowling half joints and struts.

g. Paragraph 38b. The ice accretion of the Phase II engine nose cowling may result in engine damage. In the Phase II modification a 9.0 KVA alternator was installed and the duty cycles of certain heater elements were further increased. In moderate icing encounters, ice still formed on the cowling half joints and struts.

h. Paragraph 38c. The ice accretion characteristics of the Phase III configured No. 1 engine cowling may result in engine damage. In Phase III testing No. 1 engine element ON times remained the same as Phase II, but the duty cycle of one engine No. 2 element was increased. Sufficient heat was not available to modify the heating elements of both engines. In natural icing tests, at light icing conditions, ice continued to form on the No. 2 engine half joints and struts.

i. Paragraph 38d. Ice accretion on the tip of the propeller spinner may possibly be ingested through the engine inlet. The tip of the spinner is not heated and a "donut" of ice forms on the tip. This "donut" builds and is ultimately shed at unpredictable intervals. Although no ingestion occured, the possibility of it happening remains.

j. Paragraph 38e. The lack of an adequate engine ice protection system status indicator. Any improvement to the OV-1D ice protection system should incorporate an indication to the pilot that all heating elements are operational.

k. Paragraph 38f. The ineffective propeller ice protection system. The existing blade heaters are inadequate in the amount of heat applied as well as the total area of the blade that is protected.

l. Paragraph 38g. Damage to the airframe and stores caused by ice shedding from the propellers. Any deicing system, which allows the periodic build-up and shedding of ice, can cause aircraft damage because of the shed ice.

3. The deficiencies and shortcomings identified during the OV-1 icing tests require correction. Until such time as correction can be incorporated and verified through flight tests, the aircraft should be restricted. Based on the results of the flight tests OV-1 users should be alerted to the potential hazards of operating in icing conditions. The following recommendation, warning, and notes should be issued in an operational Safety of Flight message and incorporated in the Operator's Manual as soon as possible:

Continuous flight into light or more severe icing conditions is not recommended.

WARNING

When flying in icing conditions if the indicated airspeed decreases as much as 15 knots within a 5 minute period or decreases to 145 knots with a power setting for maximum range airspeed, the aircraft ice protection systems may become ineffective and the icing conditions should be exited immediately.

NOTE

Under certain icing conditions, the windshield wipers and anti-ice system may become ineffective and field of view through the front windshield may be inadequate. When these conditions exist with below freezing temperature at ground level, a landing may be required with visual cues limited to those available only through the cockpit entrance hatch and windshield quarter panel.

DRDAV-D
SUBJECT: Directorate for Development and Qualification Position of the Final Report of USAAEFA Project No. 81-21, Limited Artificial and Natural Icing Tests of the OV-1D (Re-Evaluation)

NOTE

> When flying in icing conditions and an asymmetric propeller ice shed occurs, as evidenced by a sudden increase in airframe vibration, the propeller out-of-balance condition and the vibration may be reduced by cycling the propeller speed from minimum to maximum RPM for 4 to 5 cycles. Engine torque and propeller speed should be monitored when moving the propeller levers to avoid an overtorque or overspeed condition.

4. This test program was undertaken to determine the adequacy of the Phase I, II, and III improvements and the modifications were the best that could be accomplished quickly, short of major redesign of the aircraft's ice protection systems. Although the modifications offered improvements, for the reasons stated above, they are not recommended for incorporation either as an interim or final fix. An ice protection system which includes a redesigned engine cowling, propeller and spinner heating, a windshield anti-ice system, and adequate generator capacity is recommended. Any redesigned ice protection systems incorporated on the OV-1 will require additional airworthiness qualification for flight into icing conditions.

FOR THE COMMANDER:

CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

OV-1D Mohawk

TABLE OF CONTENTS

APPENDIXES

DISTRIBUTION

INTRODUCTION

BACKGROUND

1. The US Army Aviation Engineering Flight Activity (USAAEFA) was tasked by the US Army Aviation Research and Development Command (AVRADCOM) to plan, conduct, and report on a limited artificial icing test of the OV-1D aircraft during the 1980-1981 icing season. An evaluation of the OV-1D was conducted under USAAEFA Project No. 80-16, appendix H. This evaluation identified two deficiencies and four shortcomings. Grumman Aircraft Corporation (GAC) modified the anti-icing capability of the engine cowl ring and inlet struts to improve the ice accretion characteristics of the engine inlet. AVRADCOM tasked USAAEFA (ref 1, app A) to conduct a limited two-phase artificial icing re-evaluation during the 1981-1982 icing season. The first phase was with the existing OV-1D 6.5 KVA generator uprated to 7.5 KVA, insulation added to the cowling interior, and revised heating element cycle times. Phase II incorporated a 9.0 KVA generator, and additional changes to the heater element cycle times. A third phase was added after the artificial icing tests were completed. The third phase was conducted in a natural icing environment with further modification to the Phase II configuration as detailed in appendix B. Testing was conducted in accordance with the approved test plan (ref 2, app A).

TEST OBJECTIVES

2. The objectives of this test were to conduct limited icing flights on the OV-1D aircraft to:

a. Determine the ice accretion characteristics of the modified OV-1D engine cowl ring in artificial icing conditions and determine if accreted ice is subject to being ingested into the engine.

b. Verify the adequacy of the modified engine ice protection in natural icing conditions.

DESCRIPTION

3. The test aircraft was a standard OV-1D serial number 68-15932 configured with the louvered scarved shrouded suppressor (LSSS) and 150-gallon Sergeant Fletcher fuel tanks on wing stations 3 and 4 (photo in abstract). A more detailed description of the OV-1D aircraft is contained in the operator's manual (ref 3, app A). A detailed description of the modifications to the engine ice protection systems is presented in appendix B. The test aircraft

was obtained from and maintained by the US Army Aviation Developmental Test Activity (AVNDTA). An AVNDTA copilot flew during the test.

TEST SCOPE

4. Limited artificial icing tests were conducted in the St. Paul, Minnesota area from 1 February through 25 March 1982. A total of eight test flights were conducted totaling 11.7 hours of flight time. A total of 4.2 hours of actual cloud immersion time was achieved. Test conditions are presented in tables 1 and 2.

5. Natural icing tests were conducted in the Salem, Oregon area from 13 April through 3 May 1982. A total of five test flights were conducted totaling 11.1 hours. A total of 6.5 hours of actual cloud time was achieved. Test conditions are presented in table 3. Flight limitations contained in the operator's manual and in the airworthiness release (ref 4, app A) were observed during the testing.

TEST METHODOLOGY

6. Artificial icing tests were conducted by immersing the right engine in the artificial icing cloud generated by a JCH-47 configured with the Helicopter Icing Spray System (HISS). A more detailed description of the HISS is presented in appendix C. The cloud conditions were documented by a U-21 aircraft configured with cloud measuring equipment. This equipment is further described in appendix D. The test aircraft was flown at 120 knots true airspeed (KTAS) with the right engine in the artificial cloud for approximately 30 minutes. Photographic data and qualitative ice accretion characteristics were obtained from personnel in the CH-47, the U-21, and the OV-1 aircraft.

7. For the natural icing tests the U-21 aircraft located the required icing conditions prior to takeoff of the OV-1. The OV-1 was flown in the icing environment in a clean configuration, initially with cruise power (60 percent torque and 1300 RPM) which produced approximately 190 KTAS. The U-21 documented the test conditions and provided air-to-air photo documentation after the icing encounter. Natural icing test techniques are further discussed in appendix D.

Table 1. Artificial Icing Test Conditions
Phase I

Flight Number	Temperature (°C)	Average Liquid Water Content (g/m^3)	Median Volumetric Diameter (microns)	Relative Humidity (percent)	Time in Cloud (hour)	Remarks
1	-20	.48	29	67	0.6	7.5 KVA gen installed
2	-19.5	.59	25	56	0.3	abort for HISS
3	-4	.98	78	88	0.8	

Table 2. Artificial Icing Test Conditions
Phase II

Flight Number	Temperature (°C)	Average Liquid Water Content (g/m^3)	Median Volumetric Diameter (microns)	Relative Humidity (percent)	Time in Cloud (hour)	Remarks
4	-5	1.04	47	95	0.5	9 KVA gen installed
5	-10.0	.82	71	9	0.5	
6	-12.5	.61	37	60	0.6	
7	-16.0	.56	36	65	0.5	
8	-20.0	.59	31	80	0.5	prop spinner duty cycle modification

Table 3. Natural Icing Test Conditions
Phase III

Flight Number	Temperature (°C)	Average Liquid Water Content (g/m^3)	Median Volumetric Diameter (microns)	Time in Cloud (hour)
Ferry	-11.0	0.30	22	0.2
	-11.0	0.50	10	0.1
1	-7.5	0.28	33-240	0.8
	-7.5	0.18	16	0.7
2	-10.5	0.20	13	0.6
3	-7.0	0.30	23	1.3
4	-9.0	0.35	17	1.9
5	-13.0	0.20	21	0.9

RESULTS AND DISCUSSION

GENERAL

8. A three-phase icing evaluation was conducted on the OV-1D. Phase I was an artificial icing test in which the anti-ice generator output and heater element ON times were increased beyond the standard OV-1 configuration. Insulating foam was also added to the engine inlet fixed and removable cowling to aid in heat retention. This configuration improved engine inlet ice accretion characteristics. Phase II was an artificial icing test in which a new anti-ice generator was installed with further increases in heater element ON times. The Phase II changes produced additional improvement. Phase III modifications consisted of additional element ON time changes and foam was added to the inlet cowling struts. The Phase III tests verified the improved engine inlet anti-ice capability of the final configuration in a natural icing environment. However, ice still accreted on the No. 1 engine cowl, and both propeller spinners, propeller blades, and propeller spinner afterbodies. Aircraft peformance was severely degraded in some icing conditions, probably due in part to ice formation on the propeller blades. Pilots flying the OV-1D should take steps to exit the icing environment if certain performance degradations are observed. During this evaluation, two deficiencies and seven shortcomings were identified. The deficiencies are the inability of the windshield anti-ice system to clear the windshield, and the accumulation of significant amounts of ice on the propeller spinner afterbody where it has a high probability of being ingested into the engine and causing damage. Three of the shortcomings are: Phase I, Phase II and No. 1 engine Phase III nose cowling ice accretion characteristics may result in engine damage. The other shortcomings are: 1) the airframe and stores damage caused by ice shedding from the propellers; 2) ice formation on the tip of the propeller spinner; 3) ineffective propeller ice protection system; and 4) lack of an adequate engine inlet ice protection system status indicator.

ARTIFICIAL ICING

Phase I (7.5 KVA Generator)

9. Only three flights were conducted during this phase, one of which was aborted after 15 minutes cloud time because of HISS problems. The Phase I system is described in appendix B.

Engine Nose Cowling Assembly:

10. The ice accretion characteristics of the nose cowling assembly were evaluated in moderate icing conditions behind the HISS at conditions listed in table 1. Ice buildups were observed on heated surfaces inside the engine nose cowling on both flights. Ice

accreted inside and outside the engine air inlet along the 10 and 4 o'clock joints between the fixed and removable nose cowl assemblies. After 30 minutes immersion in the cloud, ice accretions at the cowling joints were approximately 1/4-inch thick and extended approximately 1 inch to either side of the joint (photo 1, app F). Ice accretions were observed during flight on the front and sides of the three-nose cowling struts (photo 1). The ice accretions were evident at both temperatures tested with the largest accretions at -20°C. Ice accretions were also observed inside the engine cowling inlet from 5 to 7 o'clock. The ice accretion characteristics of the Phase I engine nose cowling may result in engine damage and is a shortcoming. However, this configuration was an improvement from the results seen in appendix H.

Phase II (9.0 KVA Generator)

11. Five flights were conducted during this phase. Phase II system modifications are described in appendix B.

Engine Nose Cowl Assembly-External:

12. The ice accretion characteristics of the external surface of the engine nose cowling assembly were evaluated at the conditions lised in table 2. Representative data are presented in photos 2 through 4, appendix F. Ice was not observed on the heated portion of the cowling except at the cowling joints. However, ice did accrete just aft of the heated portion. Liquid water was observed running back on the outside of the cowling and freezing on the unheated surfaces at all temperatures (photo 2) but was not considered to be a problem. At temperatures warmer than -10°C, a small amount of ice (1/4-inch thick) was observed on the cowling joints. At -15°C, this ice formation became larger (1/2-inch) and extended around the leading edge of the engine inlet (photos 3 and 4). Ice accretion characteristics of the external engine nose cowl assembly is considerably improved over the standard system (photo 2, app F). However, ice still forms on the Phase II cowling joints and extends around the leading edge of the cowling where it could break off and cause engine damage and is a shortcoming.

Engine Nose Cowling Assembly-Internal:

13. The ice accretion characteristics of the inside of the engine nose cowling, particularly the cowl struts, were evaluated at the conditions defined in table 2. Photographic data is presented in photos 5 through 8, appendix F. Ice was observed inside the engine inlet or on the cowling struts at -5, -10, -12.5, and -20°C. Normally, the ice build-up was small, (about 3/4-inch thick) and usually observed on the 2 o'clock cowling strut

(photos 5 and 6). There was no ice observed on the sides of the strut or where the cowling strut joins the outer cowl such as with the standard system (photos 3 and 4, app H). At approximately 27 minutes into one icing encounter, the ice shed from the 2 o'clock strut. Photos 7 and 8 show the strut just prior to and after the shed, respectively. Although the shed was not observed, the only place the ice could go was into the engines. The ice accretion characteristics of the inside of the engine nose cowling assembly are improved with the Phase II system modifications over the standard system, but ice still forms in the engine inlet and could cause engine damage and is a shortcoming.

Propeller Spinner:

14. The propeller spinner ice accretion characteristics were evaluated at the conditions listed in table 2. Documentation is presented in photos 3, 9 and 10, appendix F. Some small slivers of ice formed on the sides of the spinner at temperatures colder than -12.5°C (photos 3 and 9). At all test conditions, ice formed on the forward end of the spinner. This ice was 1 to 2 inches thick and formed in the shape of a donut conforming to the shape of the spinner tip (photos 9 and 10). This ice departed the spinner when the outside air temperature was above freezing. Over a given period of time, the higher LWC's produced a larger ice donut on the tip of the prop spinner as compared to lower LWC's. However, no concrete correlation can be made to the thickness of the ice and LWC since particle size and frequency of ice sheds also influence the size of the donut. It is possible that this ice might be ingested through the engine inlet; however, this was never observed. On two occasions, the observer saw the ice depart. Flight conditions were 1500 feet per minute descent, low power, 1400 RPM propeller speed, and 150 knots indicated airspeed (KIAS). Both times, the ice donut departed over the cowling, well clear of the engine inlet. On one occasion it passed through the plane of the propeller intact. On the last flight, the duty cycle of the propeller spinner heating elements was reduced to allow more heating of the propeller butt boot. The final flight was at -20°C and evidence of changes in spinner ice accretion characteristics was inconclusive. The formation of ice on the propeller spinner tip is a shortcoming.

Propeller Blades:

15. The ice accretion characteristics of the propeller blades were evaluated at the conditions in table 2. Photographic documentation is presented in photos 10 through 12, appendix F. Ice formed on the propeller, butt boots, and blades at all conditions tested. At -20°C ice accreted on the blade to about

75 percent span (photo 11). Ice thickness up to 1-1/2 inches on the blade was measured after landing (photo 12). It was not possible to document the thickness of the ice which accreted on the prop at all test conditions due to in flight shedding. The propeller butt boot, which is electrically deiced, accreted ice as if it were not heated. For the last flight, the duty cycle of the blade butt boot was increased 400 percent. There was no observed improvement. This is probably due to the heat sink capacity of the aluminum blade dissipating the heat energy of the boot before it could melt the ice bond. The propeller blades randomly shed ice which created moderate air frame vibrations and damaged the skin of the fuselage and drop tank. Damage to the airframe and stores caused by ice shedding from the propellers is a shortcoming.

Engine Damage

16. The engine was visually inspected after each flight. There was no evidence of engine damage found during the artificial icing tests.

Temperature Survey

17. Temperature sensitive tape was placed at various locations on the engine cowling and anti-ice generators. The locations are shown in figure 1, appendix E. Readings taken after each flight are presented in table 1, appendix E.

Windshield Ice Protection System

18. The engine bleed air operated windshield defog and the windshield alcohol anti-icing systems were turned on prior to entering the artificial icing conditions. Although the systems were operating, the forward visibility through the pilot's and copilot's windshield was distorted and severely reduced. The windshield defog system was used to determine its effectiveness in deicing the windshield. It was not effective and with the windshield defog on maximum, the cockpit temperature was uncomfortably hot, even though the pilot and observer did not wear cold weather clothing. The windshield alcohol system was useless at -20°C and caused ice slush which was smeared over the windshield at warmer temperatures. Centering the windshield wiper on the pilot's windshield prior to entering the cloud on one flight provided a clear area approximately 1 by 2 inches in the center of the windshield. Landing under these conditions will significantly increase the pilot's workload in an existing high workload situation. Failure of the windshield ice protection system to clear the windshield sufficiently to provide adequate

forward visibility after encountering icing conditions is a deficiency (para 25) as was identified in appendix H.

NATURAL ICING - PHASE III

19. Five Phase III configuration natural icing flights were conducted at the conditions specified in table 3. The Phase III engine ice protection system modifications differed between the No. 1 (left) and No. 2 (right) engines. These Phase III modifications are described in appendix B.

Engine Nose Cowling Assembly

20. Documentation of the No. 1 and No. 2 engine nose cowling assembly ice accretion characteristics is presented in photos 13 through 15, appendix F. A small piece of ice, approximately 1/4-inch wide and 1/4-inch thick, accreted on the No. 1 engine inboard cowling half joint leading edge at each of the conditions tested. A typical ice accretion on the inboard cowling half joint is shown in photo 13. This ice would periodically break-off and was probably ingested into the engine although no engine damage was observed during post flight inspections. An ice formation occurred on the No. 1 engine cowling half joint, but not on the No. 2 engine. This could be due to lower heat transfer to this area since on the No. 1 engine, element D1 is ON only 50 percent of the time and/or the gap between the fixed and removable cowl halfs was greater than the No. 2 engine. Both engine cowling struts and inlet interior appeared to be free of ice as viewed from the chase aircraft (photos 14 and 15, app F). The No. 2 engine inlet including the cowling half joints, leading edge, inlet interior, and cowling struts appeared to be free of ice at the conditions tested. The absence of ice on the cowl half joint leading edge of the No. 2 engine is probably due to better heat transfer in this area resulting from element D1 being ON continuously and/or the closer fit between the fixed and removable cowl halfs. The Phase III configuration of the No. 2 engine nose cowling assembly exibited the best ice accretion characteristics of all the configurations tested. However, ice still forms on the Phase III configured No. 1 engine cowling joints and extends around the leading edge of the cowling where it could break off and cause engine damage and is a shortcoming. It should be noted that -13°C was the coldest natural icing condition tested. Past experience has shown the colder the ambient temperature the more heat required to keep the inlet free of ice. Since natural icing conditions may be found at temperatures colder than -13°C, consideration should be given to further natural icing tests to evaluate the ice accretion characteristics at colder temperatures.

Propeller Spinner

21. Typical ice accretion characteristics of the propeller spinners are documented in photos 13 through 16, appendix F. Throughout the Phase III testing both propeller spinners remained relatively free of ice except for the tip of the spinners which accreted a donut-shaped ice formation. A comparison of the No. 1/No. 2 propeller spinner ice donuts is shown in photos 13 and 16, and photos 14 and 15, appendix F. The ice donut on the No. 1 propeller spinner tip never became as large as the ice donut accreted on the No. 2 propeller spinner. This is probably due to the forward heating elements in the No. 1 propeller spinner (prop leg 2) being energized approximately 87 percent of the time compared to only 50 percent of the time for the No. 2 propeller. Both propeller spinners shed their ice donuts several times during the icing encounter with the No. 1 engine donut shedding more frequently. The sheds normally occurred when a propeller out-of-balance condition was induced by assymetric propeller blade ice shedding. The propeller spinner ice donut sheds were not visually witnessed each time; however, on two occasions during level flight the ice donut was observed when it departed the spinner - once passing above the engine cowing, clear of the engine inlet and once hitting a propeller blade and shattering. The ice accretion characteristics of the No. 1 engine propeller spinner with propeller leg 2 energized 87 percent of the time appear to be better than the No. 2 engine propeller leg 2 Phase III modification. Since a possibility exists that the propeller spinner ice donut may be ingested through the engine inlet, the ice accretion on the tip of the propeller spinner remains a shortcoming as previously reported in paragraph 14 and appendix H.

Propeller Blades

22. A typical ice build-up on the propeller blades is shown in photos 13 and 16, appendix F. The ambient ground level temperature during the Phase III testing was above freezing; therefore, no ice was left on the propellers after landing as in the Phase II testing (para 15). Assymetric propeller ice sheds resulting in airframe vibrations occurred at all conditions tested. The vibrations were immediately apparent to the crew but did not significantly affect their workload. The propeller ice sheds were random and the frequency of the sheds was a function of the icing severity. The propeller speed was varied from minimum to maximum using the propeller levers in an attempt to induce propeller ice shedding and relieve the out-of-balance

condition. This procedure was effective on two of four attempts. The following NOTE should be placed in the operator's manual:

NOTE

> When flying in icing conditions if an asymetric propeller ice shed occurs as evidenced by a sudden increase in airframe vibration, the propeller out-of-balance condition and the vibration MAY be reduced by cycling the propeller speed from minimum to maximum RPM for 4 to 5 cycles. Engine torque and propeller speed should be monitored when moving the propeller levers to avoid an overtorque or overspeed condition.

23. Phase III modifications included disconnecting the propeller blade butt boots on the No. 2 engine. The No. 1 engine propeller blade butt boot electrical heating elements were operational and in the standard configuration (13 percent, ON time). The frequency of propeller ice sheds and the amount of ice accreted on the heated and unheated propellers appeared to be the same (photo 13 (heated blades) and photo 16 (unheated blades)). The ineffective propeller ice protection system is a shortcoming.

Propeller Spinner Afterbody

24. Photo 17, appendix F depicts natural ice accretions aft of the propeller spinner on the unheated propeller spinner afterbody. This ice formation was approximately 1 1/2-inch thick and formed in an 8-inch arc at the area between the propeller spinner and the propeller spinner afterbody. A small ice buildup in the same location was observed during the 1980 engine inlet artificial icing evaluation and Phase II artificial icing behind the HISS (photo 18, app F). It was assumed the ice formation on the propeller spinner afterbody observed in the artificial icing tests was due to the high angle of attack required when flying behind the HISS at 120 KTAS. However, during one natural icing encounter at cruise airspeed significant quantities of ice did form on the propeller spinner afterbody. The test conditions were 0.28 gm/m^3, -7.5°C with cloud droplet median volumetric diameters (MVDs) ranging from 33 to 240 microns. Engine damage may occur if this ice formation was ingested by the engine. No engine damage occurred when this ice departed the propeller spinner afterbody. Due to the location and size of this ice formation, a high probability for engine damage does exist. Ice accretions on the propeller spinner afterbody may be ingested through the engine inlet possibly resulting in engine damage and is a deficiency.

Windshield Ice Protection System

25. The windshield ice protection system was evaluated throughout the natural icing tests. The adequacy of the windshield alcohol anti-icing system was a function of the type of icing environment. The amount of reduced visibility appeared to be a function of droplet size which cannot be determined by the operational pilot. A uniform small particle distribution as encountered at 0.35 gm/m^3 LWC and -9°C with 17 micron MVD did not significantly restrict the pilot's forward field of view (photo 19, app F). The icing conditions encountered at 0.28 gm/m^3 and -7.5°C with 33 to 240 micron MVD droplets totally obscured the pilot's field of view through the front windshield. The windshield anti-ice system and windshield wipers were activated prior to entering the icing cloud but were totally ineffective. Photo 20 is a pilot's view of the front windshield 5 minutes after entering the ice cloud at these conditions. Photo 21, appendix F, is a view of the windshield as seen from the chase aircraft after 45 minutes in the icing condition. Failure of the windshield ice protection system to clear the windshield sufficiently to provide an adequate forward field of view after encountering icing conditions is a deficiency as previously identified in paragraph 18 and in appendix H. The following NOTE should be placed in the operator's manual:

NOTE

> Under certain icing conditions, windshield wipers and anti-ice system may become ineffective and field of view through the front windshield may be inadequate. When these conditions exist with below freezing temperature at ground level, a landing may be required with visual cues limited to those available only through the cockpit entrance hatch and windshield quarter panel.

Oil Cooler Scoop and Splitter

26. The oil cooler scoop and splitter deice elements were disconnected during Phase I, II and III of this icing evaluation. No increase in engine oil temperature was observed due to ice accretions on the engine oil cooler or cooler inlet. The exhaust pipe shroud external air duct which serves to provide cooling air between the exhaust pipe and the wing was not instrumented to monitor temperature during the icing evaluation. Since the shroud inlet air scoop is located inside the oil cooler inlet, it is not known if an ice clogged inlet air scoop would significantly increase the temperature of the wing under the exhaust pipe. A

study should be conducted to determine if a blocked shroud inlet air scoop would have a significant impact on the wing temperature below the engine exhaust pipe.

Engine Inlet Ice Protection System Status Indicator

27. The existing engine ice protection system does not provide an indication to the pilot if the propeller, propeller spinner, or inlet cowling heating elements are operational. The only system malfunction indication is a "No. 1 and No. 2 ANTI-ICE GEN" caution light which illuminates if the generator fails. Presently a lengthy maintenance ground check is the only method to determine if the timer and all the heating elements are operating properly. An open circuit occurred on an element in the No. 1 engine inlet cowling during the Phase III testing. The open circuit was detected during the maintenance ground check after the icing flight. The single failed element was located in a non-critical area; therefore, no ice buildup occurred in this instance. However, a multiple element failure or failure of an element in a critical location may result in ice accreting in the inlet and then shedding causing engine damage. The lack of an adequate engine ice protection system status indicator remains a shortcoming, as previously reported in appendix H.

Performance and Flying Qualities

28. Throughout these tests the aircraft performance and flying qualities were qualitatively evaluated while in the icing environment. Performance degradations occurred at each icing condition encountered with the most significant loss observed at 0.28 gm/m^3 LWC and -7.5°C with MVDs ranging from 33 to 240 microns in cumuliform clouds. Large supercooled droplets such as these create high drag ice formations when contacting an airfoil surface and rapidly degrade aircraft performance. The icing condition was entered at 170 KIAS at a cruise power setting (60 percent torque per engine, 1300 RPM propeller speed). After 5 minutes the airspeed had decreased 20 knots, down to 150 KIAS. The airspeed further decreased to 135 KIAS with a cruise power setting, after having been in the cloud for 20 minutes. The wing deice boots were activated after 1-1/2 inches of ice had accreted on the wings but were only partially effective in removing the ice from the wing and tail surfaces, restoring only 5 knots of airspeed. A climb was initiated at 135 KIAS using 80 percent torque after having been in the icing conditions for 30 minutes. Maximum rate of climb was 150 feet per minute. At 135 KIAS the aircraft was in a prestall buffett with rudder and aileron control positions approximately 3 inches and 4 inches, respectively, right of the cruise trim position. The normal stall speed in this configuration

is approximately 82 KIAS. The prestall buffett airspeed observed in these tests indicates that the actual stall speed with ice on the wings may be considerably higher than that shown in the operator's manual. As the airspeed decreased from the loss of propeller and wing performance the angle of attack was increased in order to maintain altitude. Increasing the angle of attack exposed more of the underside of the wing to the inflow of water droplets resulting in high drag ice formations under the wing aft of the deice boot. This additional drag further decreased the airspeed and required a still higher angle of attack to maintain altitude. These icing conditions were more severe than the airframe ice protection system is capable of handling; therefore, the following WARNING should be placed in the operator's manual:

WARNING

> When flying in icing conditions if the indicated airspeed decreases as much as 15 knots within a 5 minute period or decreases to 145 knots with a power setting for maximum range airspeed, the aircraft ice protection systems may become ineffective and the icing conditions should be exited immediately.

29. Ice accretion on the propeller appears to be a significant contributing factor to overall decrease in aircraft performance when the icing conditions are initially entered. During a flight at 0.2 gm/m^3 and -13.0°C with 21 micron MVD droplet size, the airspeed decreased from 170 to 140 KIAS after flying in these conditions for 18 minutes. Between 25 and 31 minutes in the ice cloud, both propellers had shed ice from one of their three blades as observed by the increase in airframe vibrations. The propeller RPM was varied from minimum to maximum four times resulting in additional propeller blade ice sheds and decrease in airframe vibrations. The airspeed increased 8 KIAS when the propeller ice was shed. This observed airspeed increase due to propeller ice shedding is a qualitative assessment and no quantitative data is available since this test was not specifically designed to evaluate propeller efficiency in icing conditions. However, based on the performance increase observed after a propeller ice shed, it is believed that a propeller system with an anti-ice capability would result in significant performance improvements when operating in an icing environment. A study should be conducted to evaluate performance degradations associated with ice accretions on propellers.

Engine Damage

30. The engine was visually inspected after each flight. There was no evidence of engine damage found during the Phase III natural icing tests.

Airframe Damage

31. Propeller ice sheds occurred in all of the icing conditions tested. Ice departing the blades frequently hit the fuselage or fuel drop tanks. Photos 22 and 23, appendix F depict aircraft damage resulting from propeller ice sheds. Dents as large as 1/4-inch deep and 3 inches in diameter were observed on the drop tank (photo 22, app F). Airframe and stores damage caused by ice shedding from the propellers is a shortcoming as discussed in paragraph 15.

32. A dent approximately 1/2-inch deep and 2-1/2 inches in diameter occurred in the leading edge of the left vertical tail in icing conditions of 0.35 gm/m^3 LWC and -9.0°C (photo 24, app F). It is suspected that this dent resulted from ice shed from the wing during descent. Several vertical splits approximately 1 inch long were observed on the vertical tail deice boots throughout the course of these tests. These splits were caused by either propeller or wing ice sheds and were detected only by close inspection of the boots. The following NOTE should be placed in the operator's manual (para 8-36, subparagraph 2):

NOTE

> After flight in icing conditions, the aircraft deice boots should be thoroughly inspected for damage.

33. Voids occurred on the engine nose cowling between the aluminum body and the fiberglass imbedded with the heating elements (photos 25 through 27, app F). The failure of the bonding material was attributed to the length of time the cowling had been in service. The void areas were re-bonded and rendered serviceable.

34. A heat-retaining foam material was added to the engine inlet cowling struts for the Phase III testing. The propeller control cables are routed through the 1 o'clock cowl strut on the removable cowl half. The propeller cables rubbed the foam material during flight as observed by the chafe marks in the cowling strut (photo 28, app F). Although no damage occurred to the cables during this test they could become chafed over a longer period of time. If this foaming modification is performed on the

aircraft in the field, adequate quality control measures should be implemented to preclude propeller cables from chafing on the removable engine inlet cowling strut.

35. Three Equipment Performanace Reports (EPRs) were submitted by AVNDTA during the natural icing evaluation and are presented in appendix G.

CONCLUSIONS

GENERAL

36. The following general conclusions were reached upon completion of the limited artificial and natural icing evaluation of the OV-1 modified engine ice protection system:

a. The Phase I and II modified engine nose cowling resulted in improved ice accretion characteristics but ice still forms which may cause engine damage (paras 10, 12, and 13).

b. The No. 2 engine nose cowling assembly Phase III changes exhibited the best ice accretion characteristics of all the configurations tested (para 20).

c. Based on the performance increase observed after a propeller ice shed, it is believed that a propeller system with an anti-ice capability would result in significant performance improvements when operating in an icing environment (para 29).

DEFICIENCIES

37. The following deficiencies, as defined in appendix D, are identified and are listed in decreasing order of relative importance:

a. Ice accretions on the propeller spinner afterbody may be ingested through the engine inlet possibly resulting in engine damage (para 24).

b. Failure of the windshield ice protection system to clear the windshield sufficiently to provide an adequate forward field of view after encountering icing conditions (paras 18 and 25).

SHORTCOMINGS

38. The following shortcomings, as defined in appendix D, were identified and are listed in decreasing order of relative importance:

a. The ice accretion characteristics of the Phase I engine nose cowling may result in engine damage (para 10).

b. The ice accretion characteristics of the Phase II engine nose cowling may result in engine damage (paras 12 and 13).

c. The ice accretion characteristics of the Phase III configured No. 1 engine nose cowling may result in engine damage (para 20).

d. Ice accretions on the tip of the propeller spinner may possibly be ingested through the engine inlet (paras 14 and 21).

e. The lack of an adequate engine ice protection system status indicator (para 27).

f. The ineffective propeller ice protection system (para 23).

g. Damage to the airframe and stores caused by ice shedding from the propellers (paras 15 and 31).

RECOMMENDATIONS

39. The deficiencies listed in paragraph 37 and the shortcomings listed in paragraph 38 should be corrected as soon a practicable.

40. The following WARNING should be placed in the operator's manual (para 28):

WARNING

> When flying in icing conditions, if the indicated airspeed decreases as much as 15 knots within a 5 minute period or decreases to 145 knots with a power setting for maximum range airspeed the aircraft ice protection systems may become ineffective and the icing conditions should be exited immediately.

41. The following NOTEs should be placed in the operator's manual immediately (para 25):

NOTE

> Under certain icing conditions, the windshield wipers and anti-ice system may become ineffective and field of view through the front windshield may be inadequate. When these conditions exist with below freezing temperature at ground level, a landing may be required with visual cues limited to those available only through the cockpit entrance hatch and windshield quarter panel.

NOTE

> When flying in icing conditions if an asymetric propeller ice shed occurs as evidenced by a sudden increase in airframe vibration, the propeller out-of-balance condition and the vibration MAY be reduced by cycling the propeller speed from minimum to maximum RPM for 4 to 5 cycles. Engine torque and propeller speed should be monitored when moving the propeller levers to avoid an overtorque or overspeed condition.

42. The following NOTE should be placed in the operator's manual (para 8-36, subparagraph 2) immediately (para 32):

NOTE

> After flight into icing conditions, the aircraft deice boots should be thoroughly inspected for damage.

43. Adequate quality control measures should be implemented to preclude propeller cables from chafing on the removable engine inlet cowling strut if the inlet foaming modification is performed on the aircraft in the field (para 34).

44. Further natural icing tests should be conducted to evaluate the ice accretion characteristics at colder temperatures (para 20).

45. A study be conducted to evaluate performance degradations associated with ice accretion on propellers (para 29).

46. A study be conducted to determine if significant increase in wing temperature occurs below the engine exhaust pipe with a blocked shroud inlet air scoop (para 26).

APPENDIX A. REFERENCES

1. Letter, AVRADCOM, DRDAV-DI, 17 December 1981 with revision 1 2 April 1982, subject: AVRADCOM Test Request No. 81-21 Limited Artificial Icing Tests of the OV-1D (Re-Evaluation) and Natural Icing Tests Revision 1.

2. Test Plan, USAAEFA Project No. 81-21, *Limited Artificial Icing Tests of the OV-1D*, 8 January 1982.

3. Technical Manual, TM 55-1510-213-10, *Operator's Manual, OV-1D/ Aircraft*, 4 August 1978, with change 5, dated 9 April 1981 and Message dated 15 June 1981.

4. Letter, AVRADCOM, DRDAV-DI, 10 March 1982 with revision 1, 8 April 1982, subject: Airworthiness Release for OV-1D S/N 68-15932 for USAAEFAA Project Number 81-21, (Re-evaluation) and Natural Icing Tests.

APPENDIX B. DESCRIPTION OF THE OV-ID ENGINE INLET ICE PROTECTION SYSTEM

GENERAL

1. The 1980 OV-1D engine ice protection system ice accretion characteristics evaluation was conducted using the standard ice protection system currently on aircraft in the field. The 1982 OV-1D engine ice protection system evaluation consisted of three phases. Each phase incorporated a different modification to the existing OV-1D engine inlet ice protection system. The OV-1D Mohawk engine inlet ice protection system consists of two parts: engine inlet anti-ice system and the engine inlet cowling ice protection system. The engine inlet anti-ice system consists of engine bleed air and hot engine oil heated inlet struts and bleed air heated inlet guide vanes. The engine inlet anti-ice system was not modified for the test. Modifications were made to the engine inlet cowling ice protection system, propeller spinner, and propeller blade butt boots. The windshield anti-ice system was serviced with Isopropyl Alcohol Grade A NSN 0810-00-543-7915. The operator's manual specifies 6-8 minutes duration in the wash cycle and 10-15 minutes in the anti-ice cycle.

EXISTING ENGINE INLET ICE PROTECTION SYSTEM

2. The engine inlet cowling system consists of a fixed and removable cowling half with electro-thermal elements imbedded in the fiberglass inlet covering. The propeller blade butt boots, the propeller spinner, and the engine oil cooler inlet lip and splitter are also electrically heated. The removable cowling half has one cowling strut through which the propeller control cables are routed. The stationary cowling half has two cowling struts. A 115 volt, 6.5 kilovolt-amphere (KVA), alternating current generator on each engine's western gearbox supplies the power to independently operate the respective engine's ice protection system. The leading edge of the nose cowling assembly, cowling struts, and engine oil cooler inlet is anti-iced continuously when the system is turned on. The remaining heating elements in the nose cowling assembly, propeller, and propeller spinner are sequentially heated in a predetermined sequence established by a timer. A schematic of the existing OV-1D engine inlet ice protection system with the element ON times is presented in figure 1.

PHASE I ENGINE INLET ICE PROTECTION SYSTEM

3. The Phase I modifications used the existing 6.5-KVA deice generator uprated to 7.5-KVA by imposing outside air temperatures (OAT) and altitude restricitons (below 0°C OAT and 12,000 feet

density altitude) on system operation. The engine oil cooler inlet and splitter elements were disconnected and the electrical power thereby saved was redistributed to increase the effective heat energy delivered to the engine inlet cowling. The oil cooler inlet and splitter elements also remained disconnected for the Phase II and III modifications. A foam insulating material was added to the fixed and removable cowling halfs (except the cowling struts) to aid in heat retention. An OAT sensor was added to alert the pilot to deactivate the deice system when temperatures were above freezing. A schematic of the engine inlet ice protection system with the Phase I modifications to the element ON times is presented in figure 2.

PHASE II ENGINE INLET ICE PROTECTION SYSTEM

4. The Phase II configuration installed two redesigned/reworked deice generators using new laminate material in the armature and stators to increase the generator rating to 9.0-KVA and eliminated a known bearing/shim interference problem. The deice timing cycles were further modified to utilize this added electrical power (fig. 3). Prop legs 1 and 2 were put on a 50 percent duty cycle for the last flight with the Phase II modification. The deice generator operation was restricted to below +4°C, 15,000 feet density altitude and gas producer power turbine speeds of 82 percent or above.

PHASE III ENGINE INLET ICE PROTECTION SYSTEM

5. The Phase III configuration differed between the No. 1 and No. 2 engines. The No. 1 engine element ON times remained the same as in Phase II (fig. 3) except element B1's ON time was increased to a 50 percent duty cycle (same as Phase I, fig. 2). The inlet cowling struts were foamed in addition to the cowling halves on both the No. 1 and No. 2 engine inlet cowlings. The No. 2 engine prop legs 1 and 2 were put on a 50 percent duty cycle and the blade butt boots disconnected (fig. 4). The power saved by disconnecting the blade butt boots was redistributed to the elements in the inlet cowling. The deice generator operation restrictions were the same as Phase II.

OV-I ENGINE INLET ICE PROTECTION SYSTEM— EXISTING

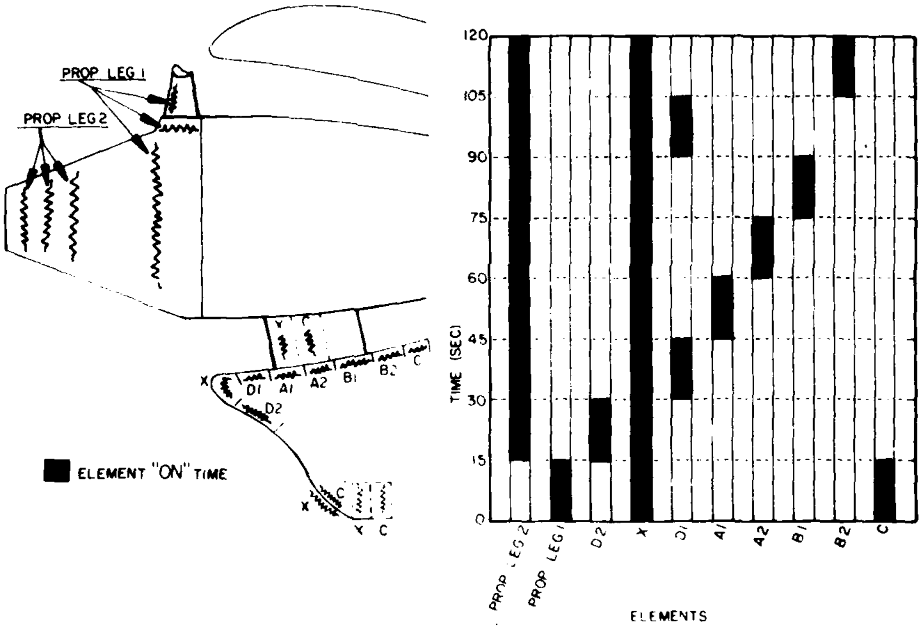


Figure 1. Engine Inlet Schematic

OV-I ENGINE INLET ICE PROTECTION SYSTEM— PHASE I

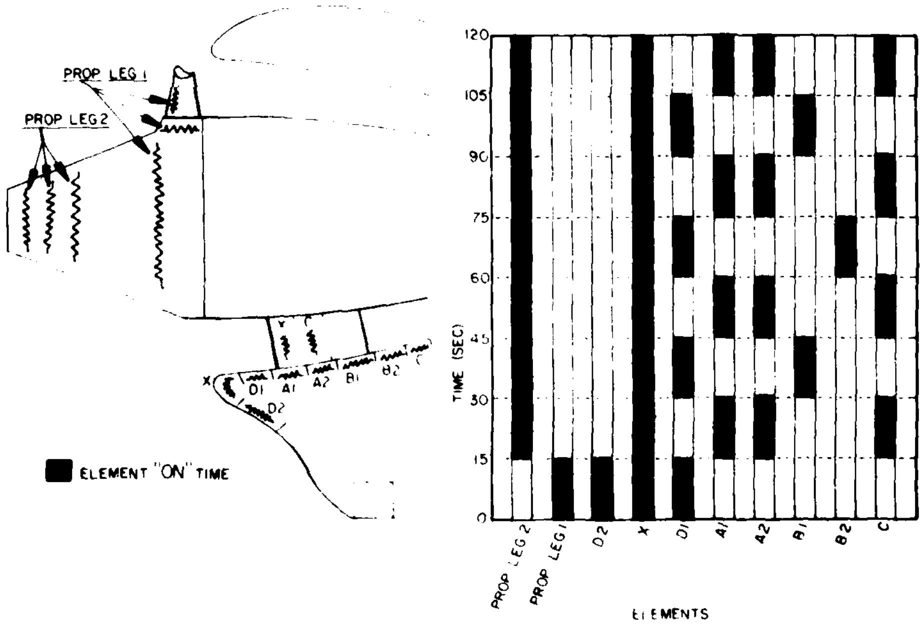


Figure 2 Engine Inlet Schematic

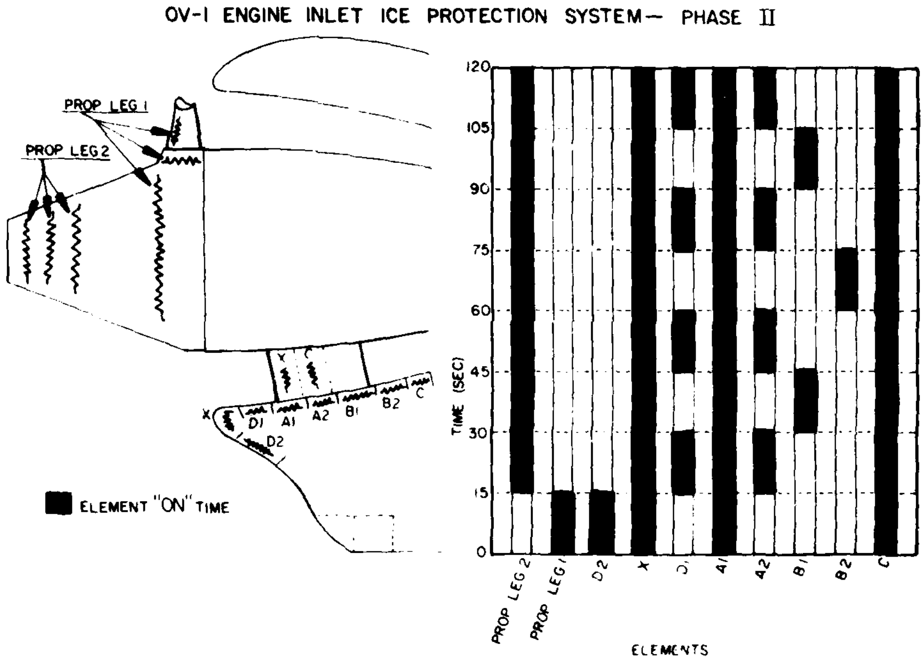


Figure 3. Engine Inlet Schematic

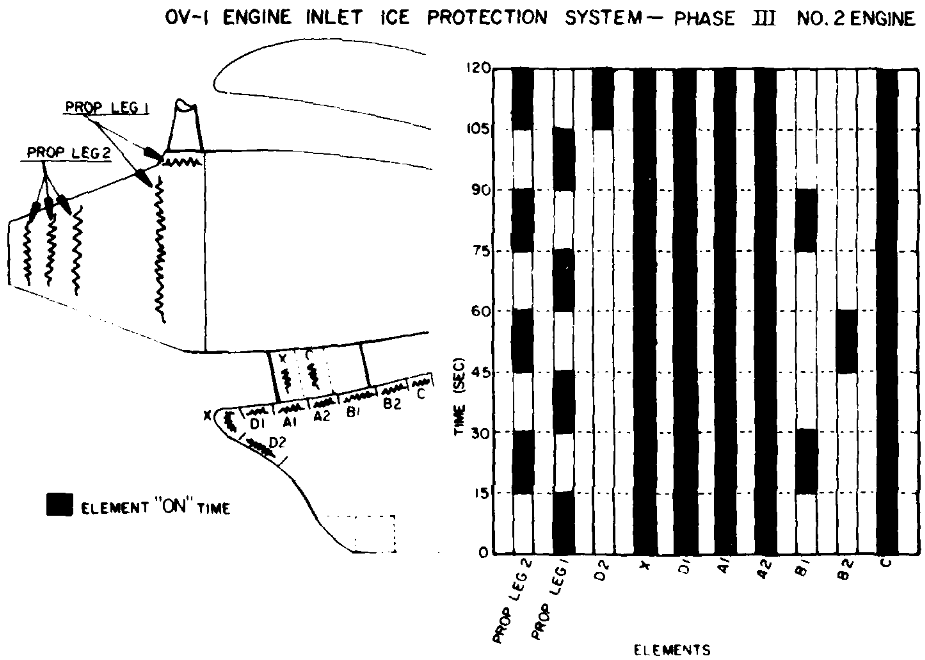


Figure 4. Engine Inlet Schematic

APPENDIX C. HELICOPTER ICING SPRAY SYSTEM (HISS) DESCRIPTION

1. The HISS is installed in a modified CH-47C helicopter and consists of an internally mounted 1800-gallon water tank and an external spray boom assembly suspended 19 feet beneath the aircraft from a cross-tube through the cargo compartment. A schematic is shown in figure 1, and a detailed description is given in references 1 and 2 below. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external boom assembly and water supply can be jettisoned in an emergency. The spray boom consists of two 27-foot center sections, vertically separated by 5 feet, and two 17.6-foot outriggers. The outriggers are swept back 20 degrees and angled downward 10 degrees giving a tip to tip boom width of 60 feet. A total of 97 Sonic Development Corporation Sonicore Model 125-HB nozzles are installed on the two center sections. The spray cloud is generated by pumping water at known flow rates from the tank to the nozzles on the boom assembly. Bleed air from the aircraft engines and an auxiliary power unit is used to atomize the water.

2. A calibrated OAT probe and a dew point hygrometer provide accurate temperature and humidity measurement. An aft-facing radar altimeter is mounted at the rear of the CH-47 to allow positioning the test aircraft at a known standoff distance. The radar altimeter is wired to red and yellow stationkeeping lights on the underside of the CH-47. These lights provide a visual indication to the test aircraft for maintaining the proper stand-off distance. Because of gross weight limitations, only 1400 gallons of water are carried. To facilitate photographic documentation during icing tests, a chemical with coloration properties similar to sea marker dye is added to the water to impart a yellow color to the ice.

3. At the 150 foot standoff distance used for icing tests, the size of the visible spray cloud is approximately 8 feet high by 36 feet wide. Water flow rates to provide a desired liquid water content (LWC) are established based on a theoretically derived formula assuming mass conservation (no evaporation). The spray cloud is then sampled to determine the actual LWC by a fixed-wing, chase/calibration aircraft equipped with particle-measuring devices. The flow rate is adjusted and the cloud is sampled until the desired average LWC is attained.

References:

1. Handbook, SM-280B, *Installation, Operation, and Maintenance Instructions with List of Parts, Helicopter Icing Spray System (HISS)*, All American Engineering Co., with Change 1, Nov 74.

2. Letter, USAAEFA, DAVTE-TI, 23 June 1982, subject: Report, Project No. 80-04-2, Helicopter Icing Spray System (HISS) Evaluation and Improvements.

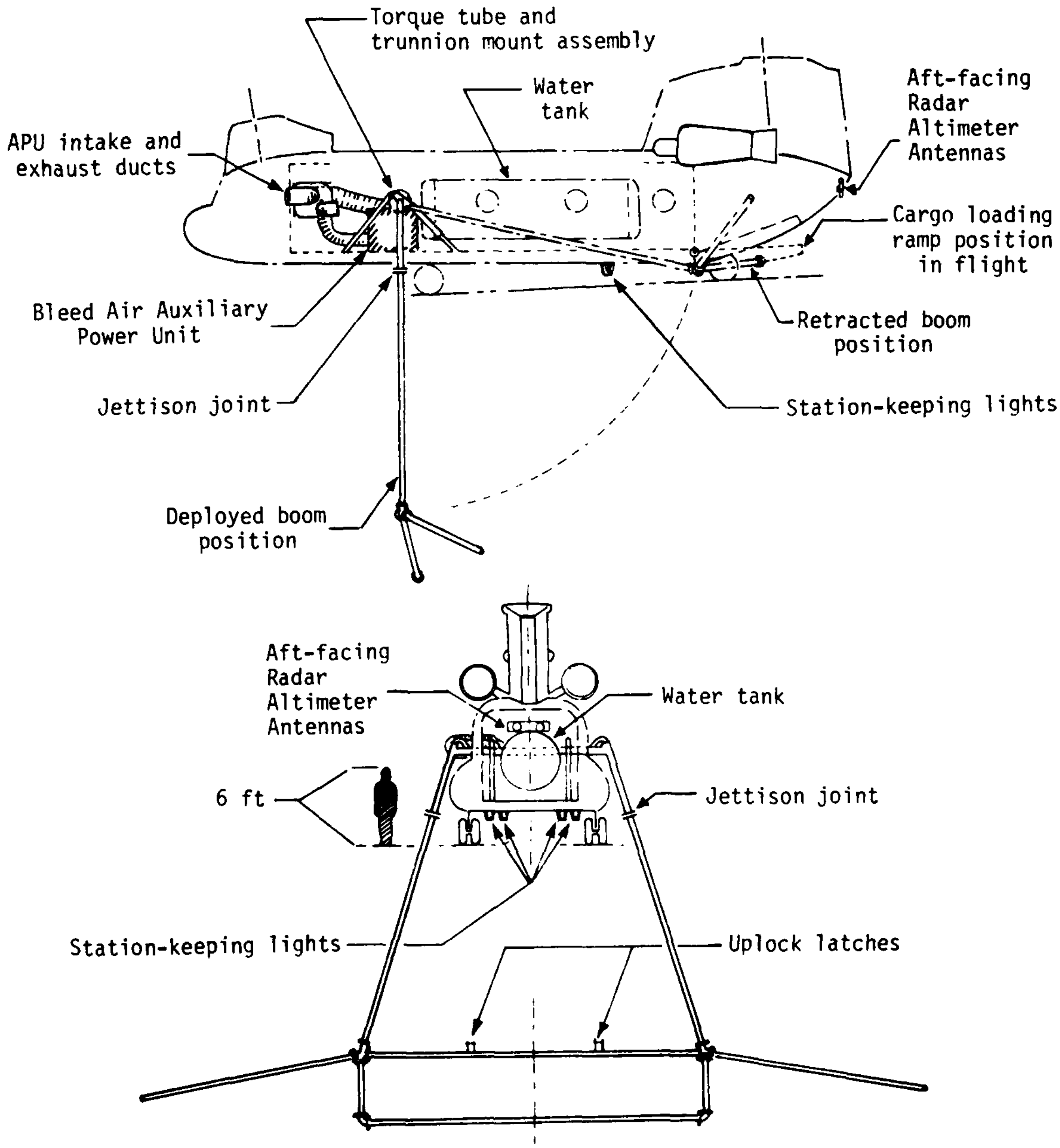


Figure 1. Helicopter Icing Spray System
Side and Rear View Schematic

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

ARTIFICIAL ICING

1. An artificial icing cloud was generated by a CH-47C helicopter equipped with a HISS. The test conditions LWC, droplet size, humidity, and air temperature) were documented by a U-21 equipped with a cloud measuring and recording system (described below). The OV-1 test aircraft flew at 120 KTAS with the right engine immersed in the cloud for approximately 30 minutes. At higher pressure altitudes the flaps were placed in the 15 degree down position. Visual observation and comments as well as photographic documentation were obtained from personnel on the rear ramp of the CH-47. This was the best location for obtaining ice accretion characteristics in the engine inlet. Observation and comments were also obtained from the U-21 chase aircraft flying alongside the test aircraft. The observer in the right seat of the OV-1 also supplied comments and photographic documentation. The observer was in an excellent location to identify ice building up on the engine cowl ring and propeller spinner. Normally, the test would terminate directly over a landing area and a rapid descent and landing would be made for further documentation of locations and quantities of ice buildup. The ground observations allowed actual measurement of ice thickness and pinpointed locations of ice building up inside the engine inlet.

2. A major advantage of this type of test was the safety element of not exposing both power plants to the ice environment. If ice accretion characteristics had caused engine damage to the right engine the aircraft could easily have flown to St. Paul Airport for a safe landing.

NATURAL ICING

3. A U-21A scout/chase aircraft equipped with a cloud particle measuring system (para 4) was used to locate and document the icing conditions. The U-21 was also configured with a bubble photographic window installed in the cabin and was used as a photographic platform to provide documentation of the ice accreted on the test aircraft. The scout/chase aircraft would locate the desired icing conditions and radio the location and icing conditions to the test aircraft before it entered the icing environment. The U-21 would then exit the icing conditions and loiter in the area to facilitate a rapid in-flight join-up with the test aircraft after it exited the cloud for photographic documentation. The OV-1 was flown in the icing environment in a clean configuration initially with cruise power (60 percent torque and 1300 RPM) which produced approximately 190 KTAS. The test

aircraft's anti-ice and deice equipment was used while in the icing conditions.

CLOUD MEASUREMENT SYSTEM

4. For cloud measurements in both the natural and artificial environments, USAAEFA employs a U-21A fixed-wing aircraft, US Army S/N 66-18008, equipped with a cloud measurement package. This package consists of the following equipment: a Particle Measuring System (PMS), forward scattering spectrometer probe (FSSP) (model FSSP-100), a PMS optical array cloud droplet spectrometer probe (OAP) (model OAP-Z00Z), Rosemount OAT sensor and display, Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh MK 10 ice detector unit with digital display, and the Small Intelligence Icing Data System (SIIDS).

5. The FSSP-100 sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused helium-neon high-order, multimode laser beam. The signal pulses are alternating current coupled to a pulse height analyzer which compares their maximum amplitude with a reference voltage derived from a separate measurement of the direct current light signal illuminating the particles. The output of the pulse height analyzer is encoded to give the particle size in binary code. The probe is set up to size particles from 2 to 47 microns having velocities between 20 and 125 m/sec (39 to 243 knots).

6. The OAP-200X sizes using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field of view. Particles are illuminated by a helium-neon laser and imaged as shadowgraphs onto the photodiode array. If the shadowing of each photodiode element is dark enough a flip-flop memory element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system. This probe contains 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns.

7. The SIIDS is a compact data acquisition system designed and programmed specifically for icing studies. It consists of four main components: a microprocessor, Techtran data cassette recorder, Axiom printer, and an operator control panel. The SIIDS has three operational modes: (1) data acquisition, in which averaged raw data are recorded on cassette tape and averaged engineering units are displayed on the printer, (2) a playback mode in which

raw averaged data read from the cassette are converted to average engineering units which are displayed on the printer, (3) monitor mode used to set the calendar clock and alter programmed constants. During data acquisition, the operator may select an averaging period of 1/2, 1, 2, 5, or 10 seconds.

8. The following parameters are displayed on the SIIDS printer in engineering units.

a. calendar: year, month, day, hour, minute and second

b. pressure altitude (feet)

c. airspeed (knots)

d. outside air temperature (°C)

e. dew point (°C)

f. total LWC observed by the FSSP (gm/m^3)

g. total LWC observed by both the FSSP and OAP (gm/m^3)

h. median volumetric diameter (μm)

i. amount of LWC observed for each channel (total 30) of both probes (gm/m^3)

DEFINITIONS

9. Results were categorized as deficiencies or shortcomings in accordance with the following definitions.

Deficiency: A defect or malfunction discovered during the life cycle of an item of equipment that consititutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued or indicates improper design or other cause of an item or part, which seriously impairs the equipment's operational capability. A deficiency normally disables or immobilizes the equipment; and if occurring during test phases, will serve as a bar to type classification action.

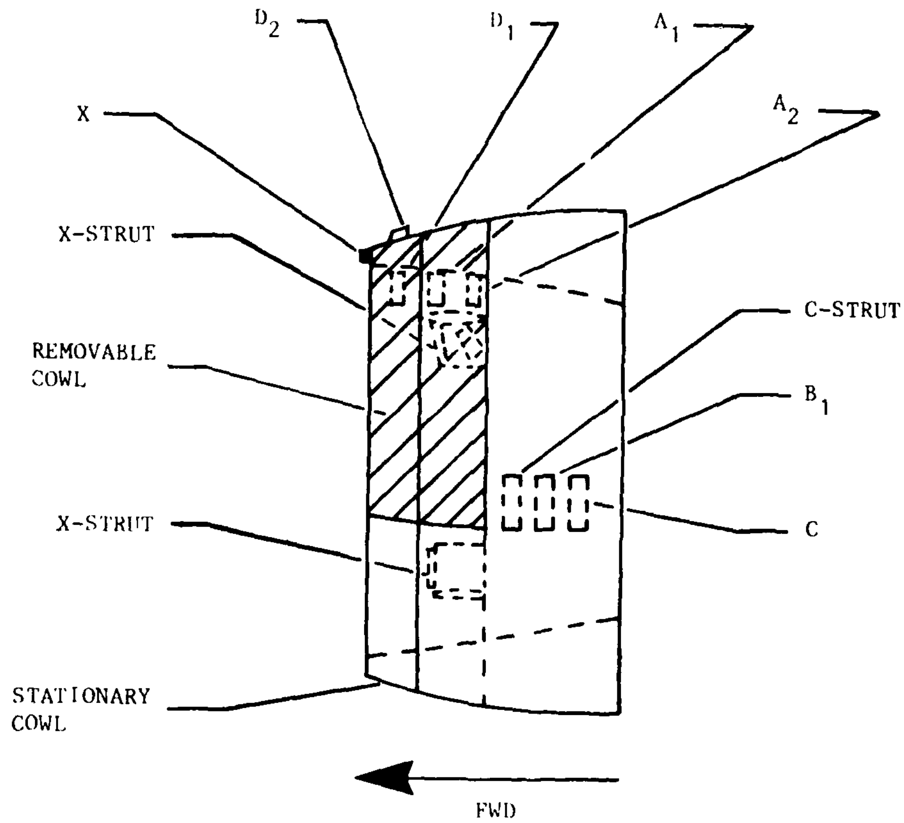
Shortcoming: An imperfection or malfunction occurring during the life cycle of equipment, which must be reported and which should be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation or materially reduce the usability of the material or end product. If occurring during test phases, the shortcoming should be corrected if it can be done without unduly complicating the item or inducing another undesirable characteristic such as increase cost, weight, etc.

APPENDIX E. TEST DATA

1. Temperature sensitive tapes were placed on the engine cowling and anti-ice generators during the icing evaluation. A summary of the maximum temperatures recorded after each artificial icing flight is presented in table 1. Physical location of the tapes are shown in figure 1.

Table 1. Maximum Temperature on Temp Plates After Each Artificial Icing Flight
(Degrees Farenheit)

Flight Number	Outside Air Temp (°C)	Pressure Altitude (ft)	A1	A2	B1	B2	C	C Strut	D1	D2	X	X Strut	#1 Gen Case	#2 Gen Case
Initial			140	140	110	110	110	110	140	110	160	150	230	200
1	-20.0	3050	140	150	110	110	110	110	140	120	160	150	230	200
2	-20.0	4000	140	150	110	110	110	110	140	120	160	170	--	--
3	-4.0	9230	150	160	110	110	110	110	160	120	160	170	230	200
4	-5.0	4000	250	220	140	160	160	130	190	250	250	--	250	230
5	-10.0	10,000	250	230	180	160	180	130	190	250	250	--	260	230
6	-12.5	9960	250	220	180	160	180	130	190	250	250	--	260	230
7	-16.0	9270	250	220	180	160	180	130	190	250	250	--	260	230
8	-20.0	9340	250	220	180	160	180	130	190	250	250	--	260	230



VIEW LOOKING OUTBOARD
RH ENGINE

TEMPERATURE RECORDINGS AT GAC, STUART, FL

ELEMENT	DEGREES F	ELEMENT	DEGREES F
X	160	A_2	140
X-STRUT	150	B_1	110*
D_2	110*	B_2	110*
D_1	140	C	110*
A_1	140	C-STRUT	110*

*OCCURRED AFTER FIRST ENGINE RUN - NO ANTI-ICE ON

Figure 1. Temperature Template Locations.

APPENDIX F. PHOTOGRAPHS

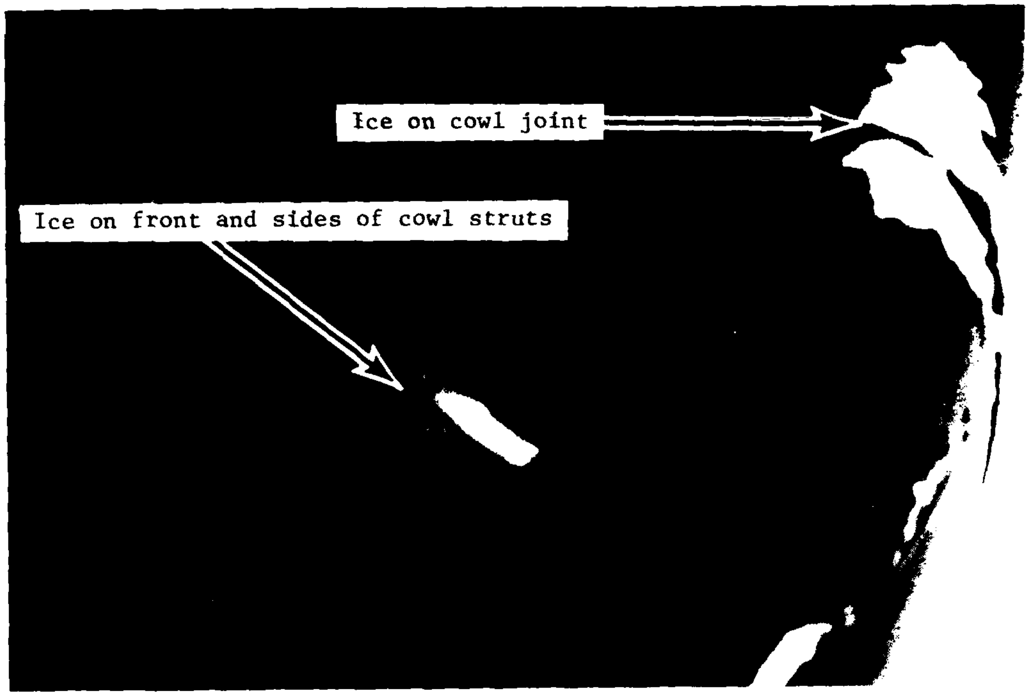


Photo 1. Artificial Icing, Phase I, -20°C, 0.48 gm/m^3

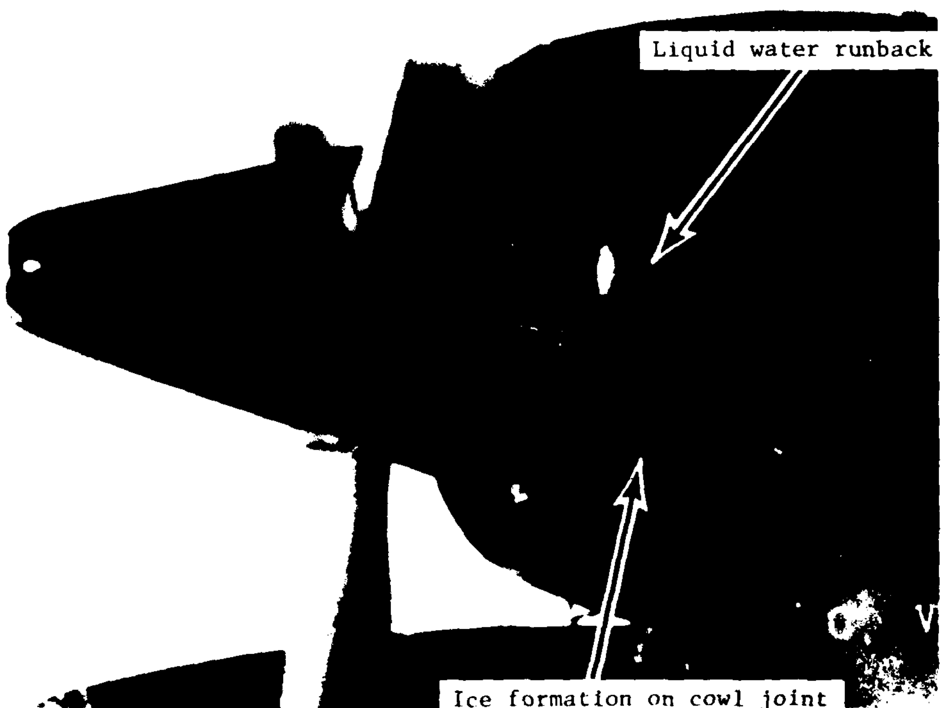


Photo 2. Artificial Icing, Phase II, -10°C, 0.82 gm/m^3

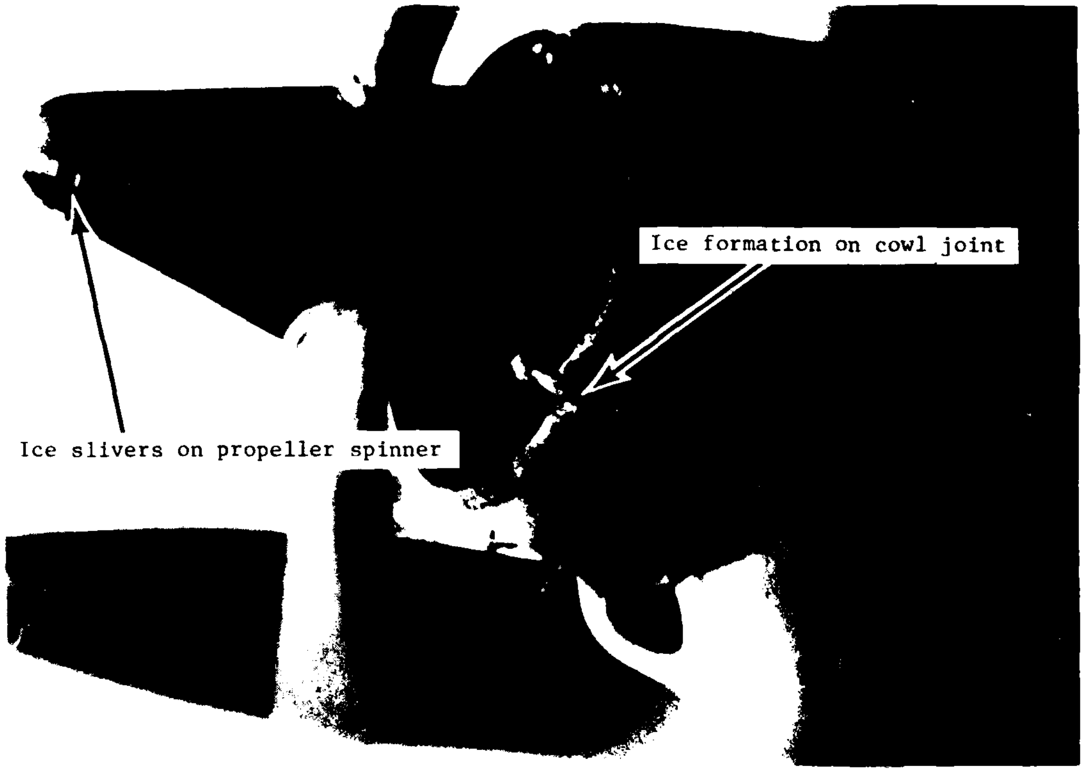


Photo 3. Artificial Icing, Phase II, -12.5°C, 0.61 gm/m^3

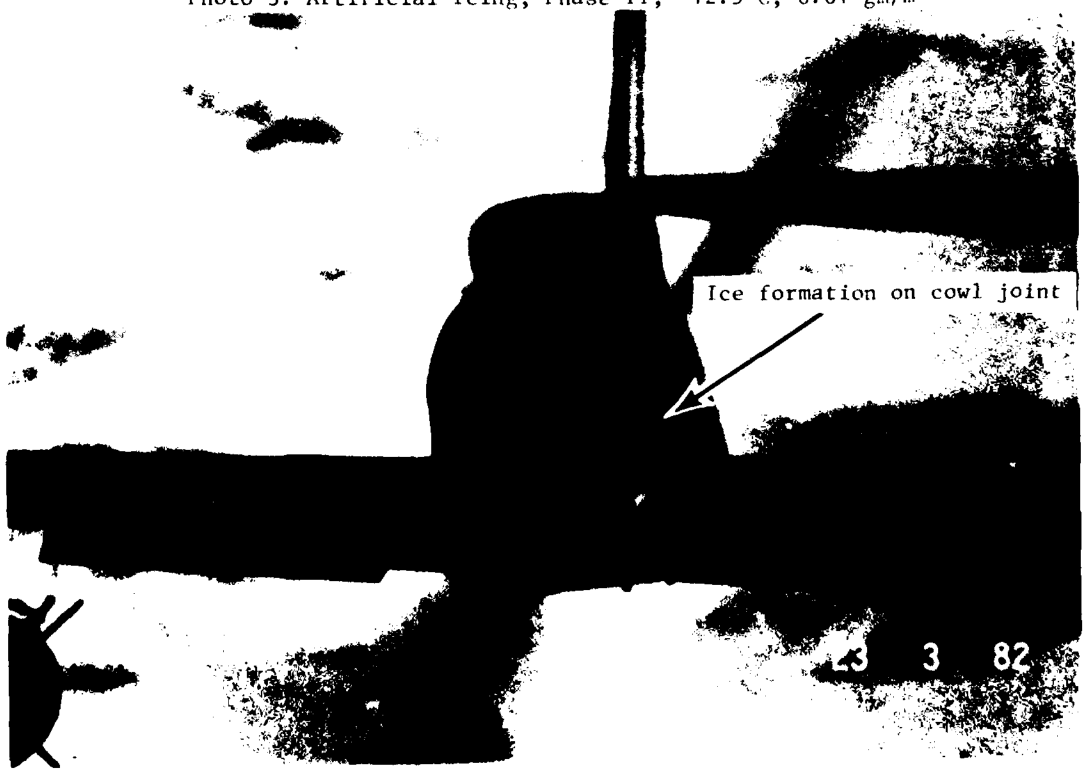


Photo 4. Artificial Icing, Phase II, -12.5°C, 0.61 gm/m^3

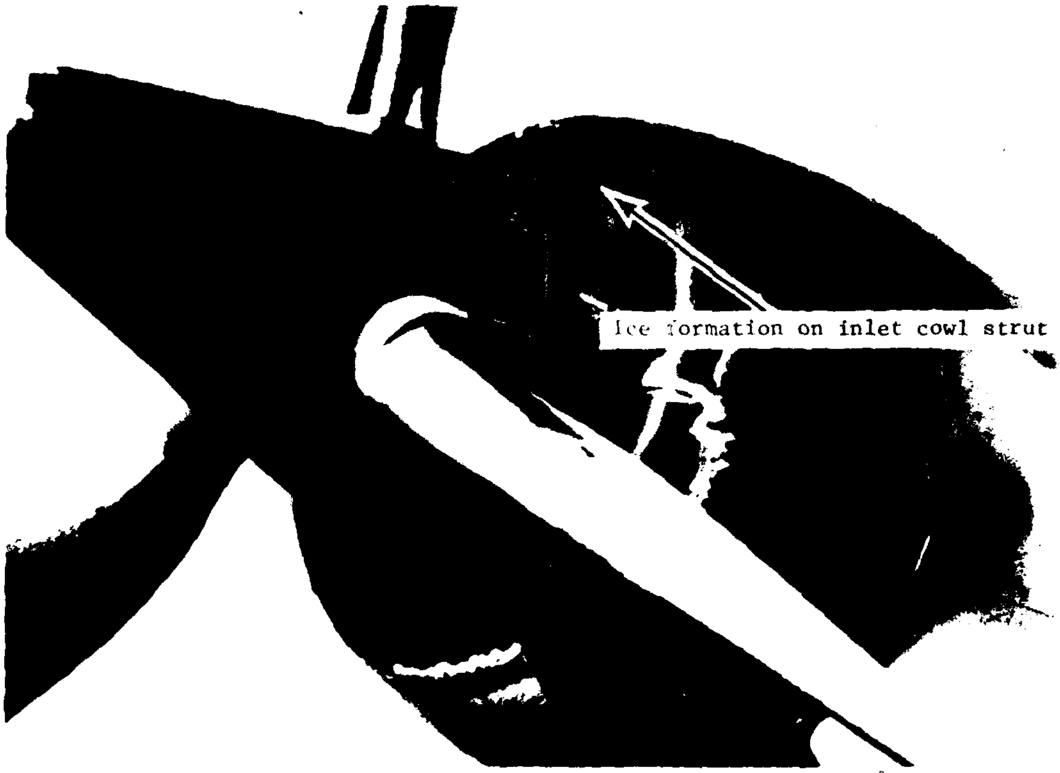


Photo 5. Artificial Icing, Phase II, -20°C, 0.59 gm/m^3

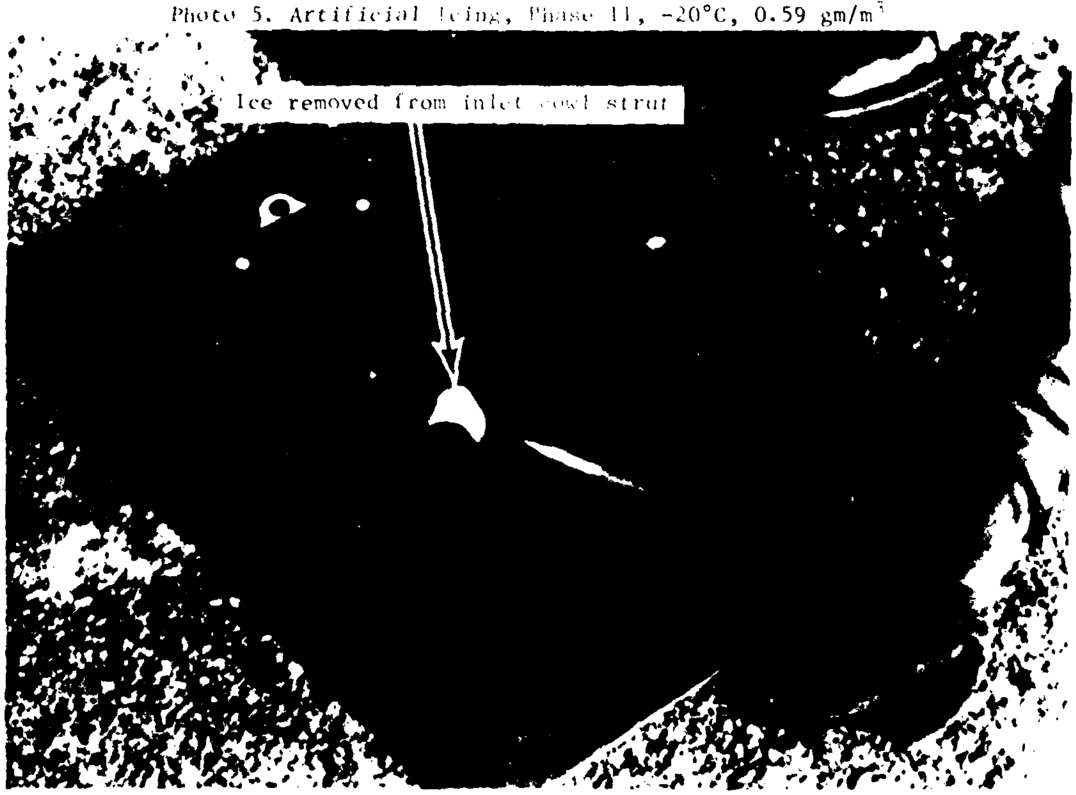


Photo 6. Artificial Icing, Phase II, -20°C, 0.59 gm/m^3

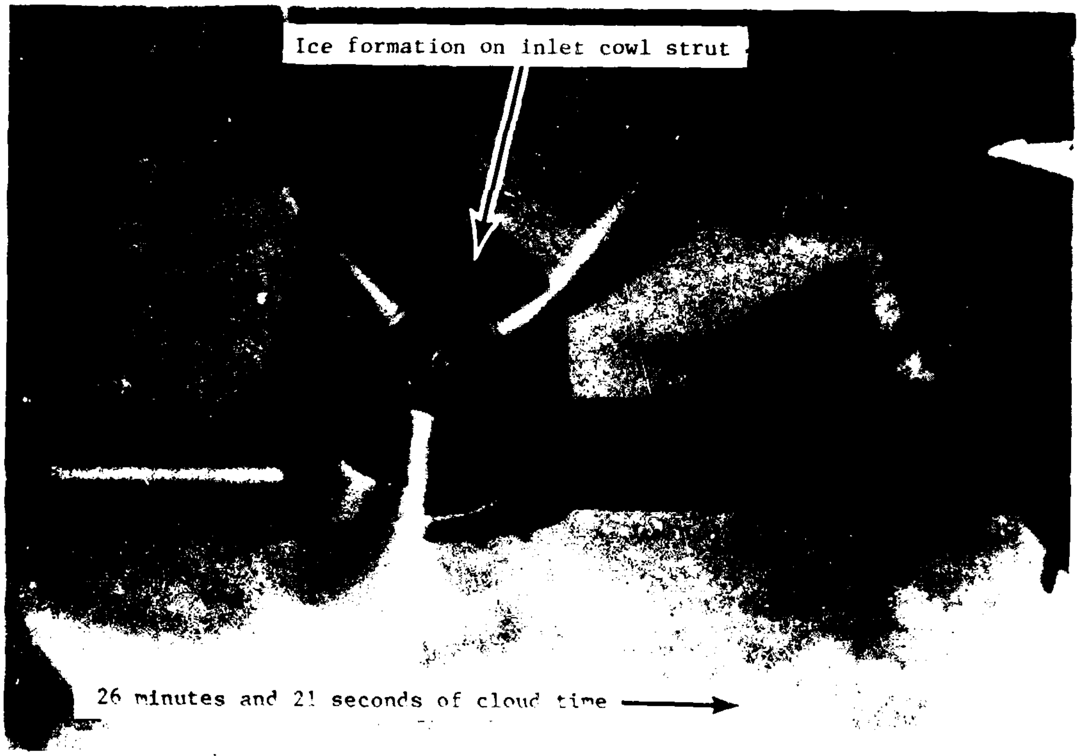


Photo 7. Artificial Icing, Phase II, -20°C, 0.59 gm/m^3

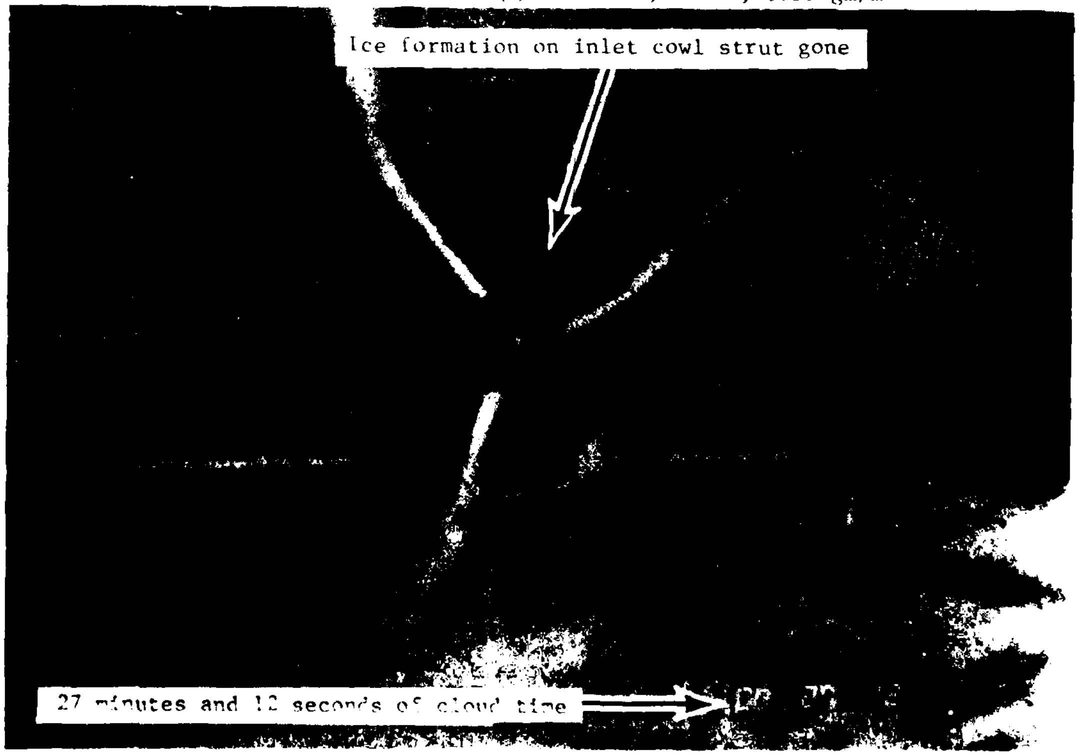


Photo 8. Artificial Icing, Phase II, -20°C, 0.59 gm/m^3

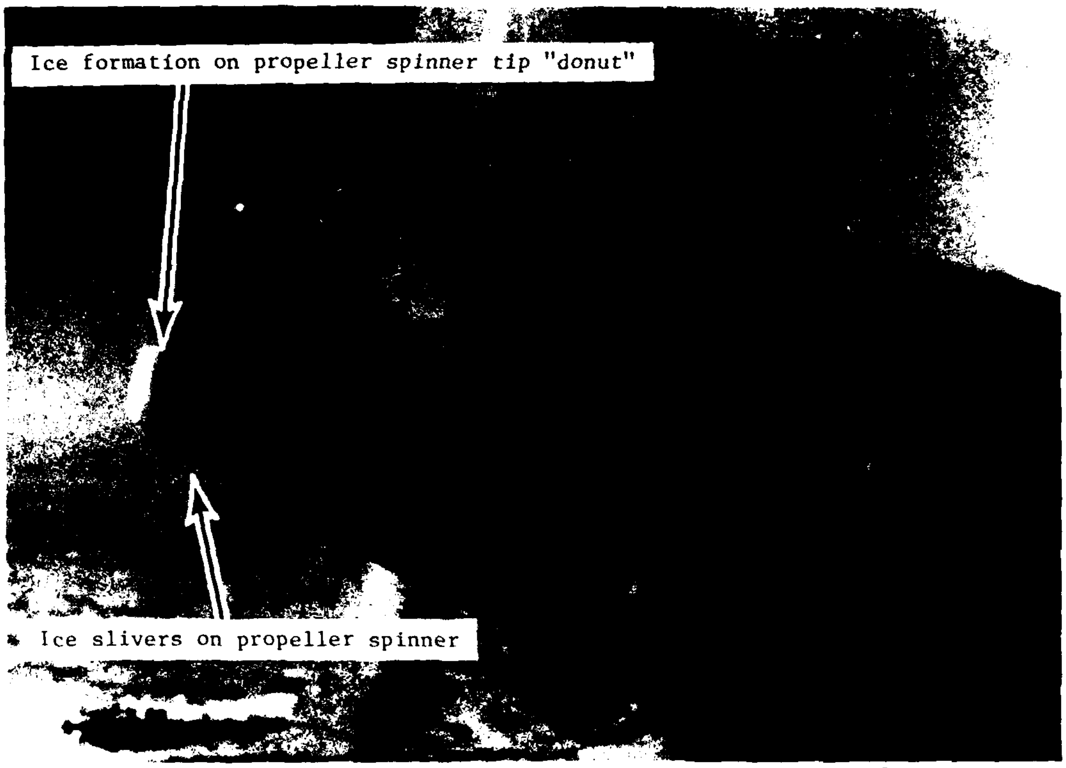


Photo 9. Artificial Icing, Phase II, -16°C, 0.56 gm/m^3

Ice formation on propeller spinner tip "donut"

Photo 10. Artificial Icing, Phase II, -20°C, 0.59 gm/m^3

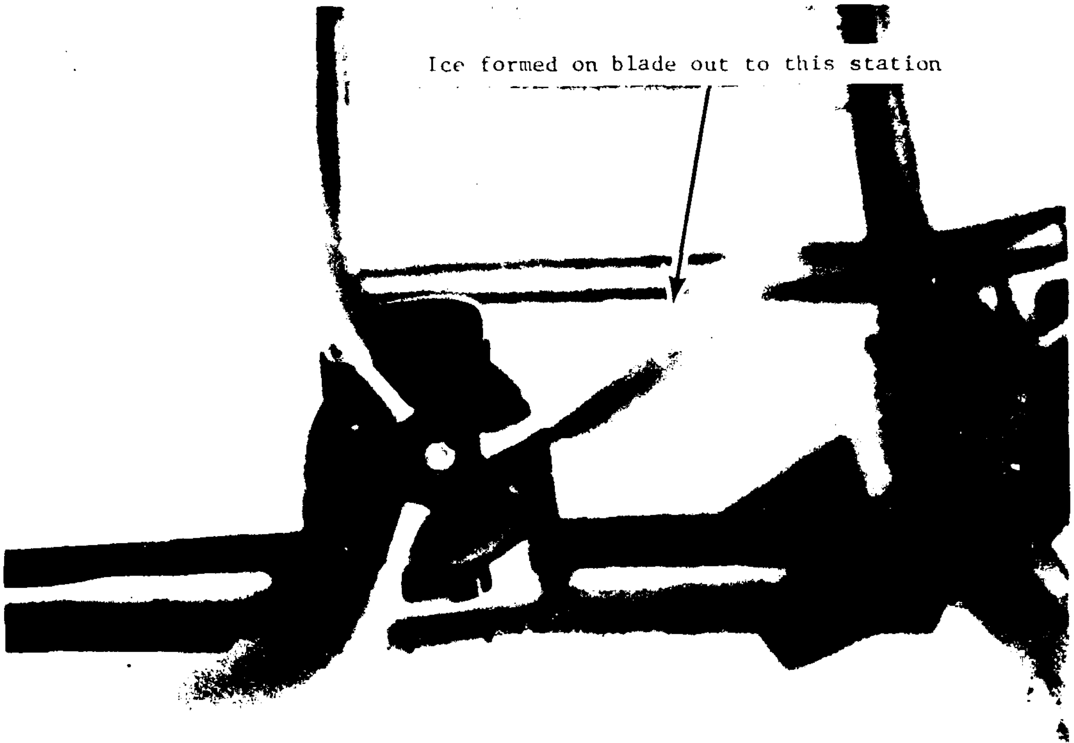


Photo 11. Artificial Icing, Phase II, -20°C, 0.59 gm/m

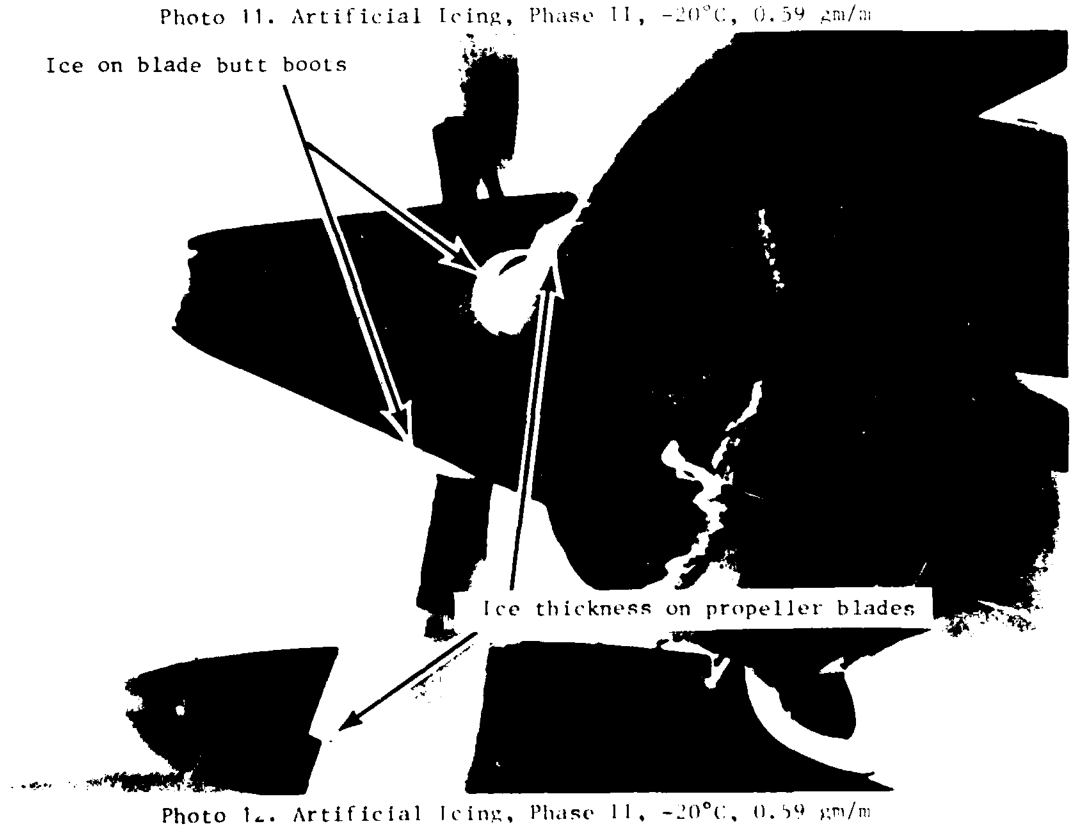


Photo 12. Artificial Icing, Phase II, -20°C, 0.59 gm/m

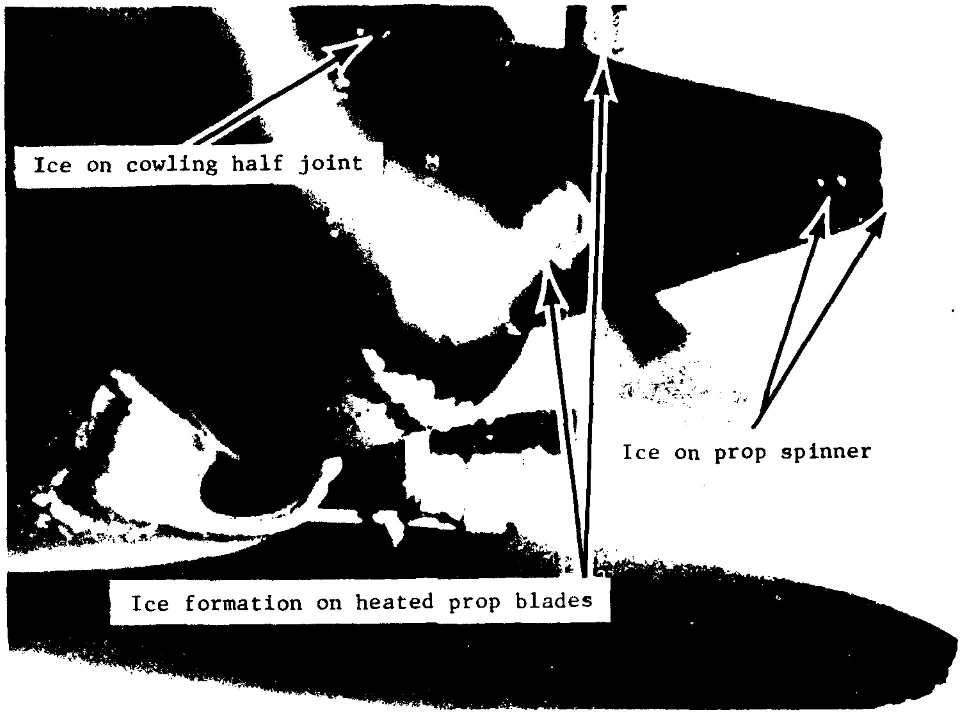


Photo 13. Natural Icing, Phase III, -13°C, 0.2 gm/m^3, No. 1 Engine

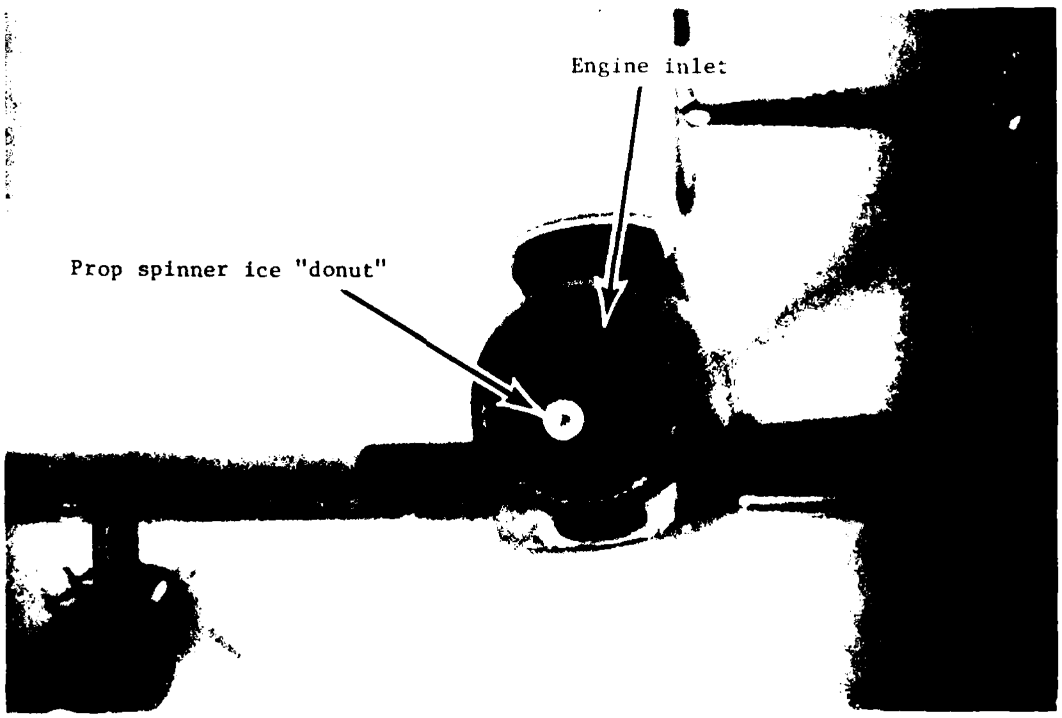


Photo 14. Natural Icing, Phase III, -13°C, 0.2 gm/m^3, No. 2 engine

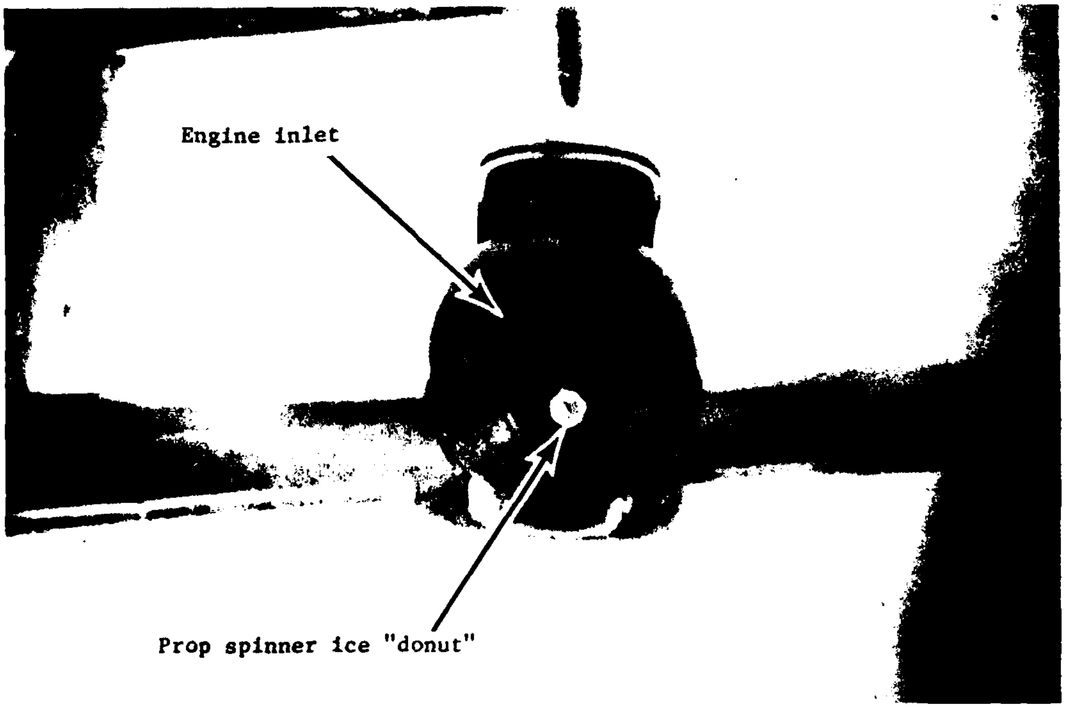


Photo 15. Natural Icing, Phase III, -13°C, 0.2 gm/m^3, No. 1 Engine

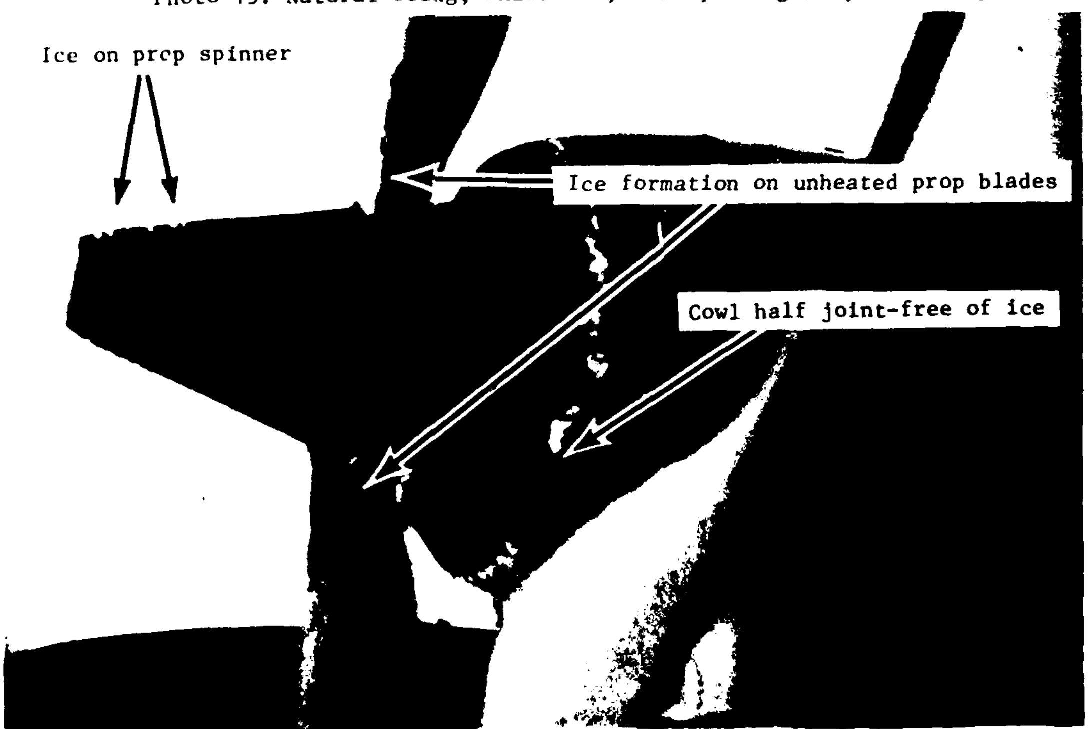


Photo 16. Natural Icing, Phase III, -13°C, 0.2 gm/m^3, No. 2 Engine

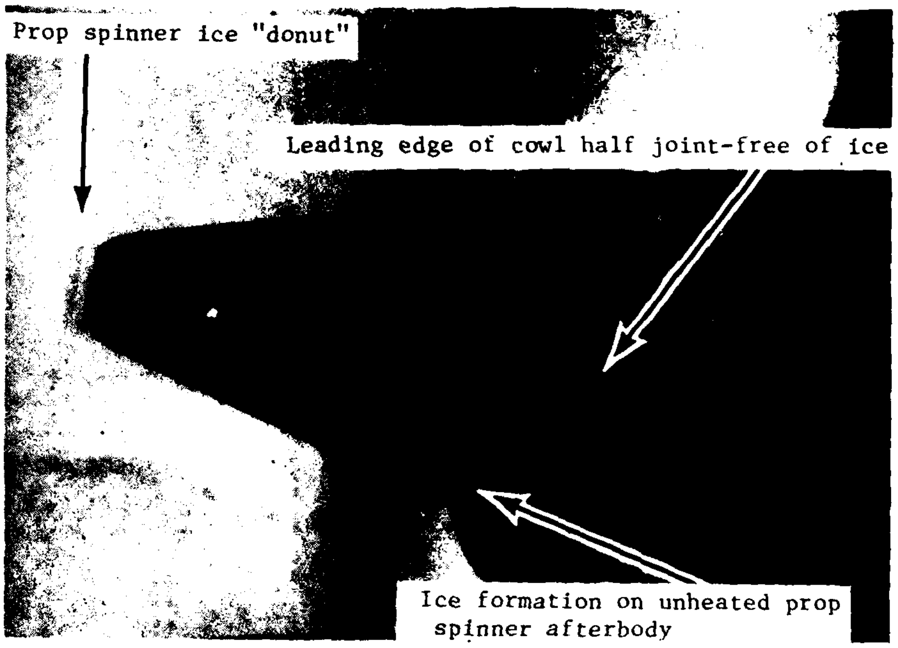


Photo 17. Natural Icing, Phase III, -7.5°C, 0.28 gm/m^3, No. 2 Engine

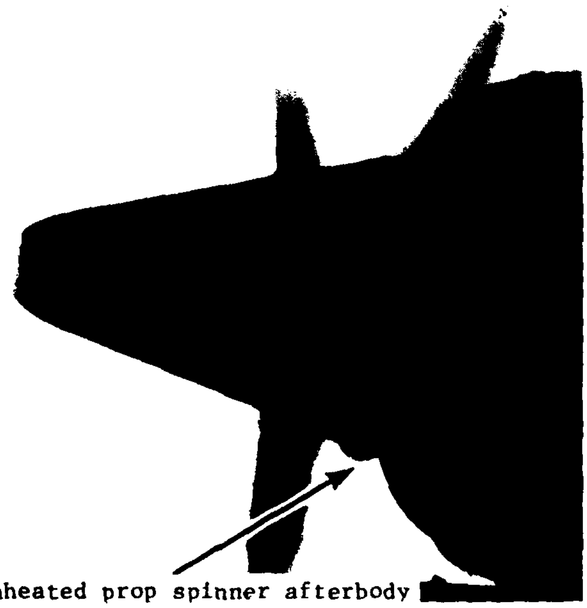


Photo 18. Artificial Icing, Phase II, °C, 0. gm/m^3, No. 2 Engine

Photo 19. Natural Icing, Phase III, -9°C, 0.35 gm/m^3, 17 micron droplet size. Windshield

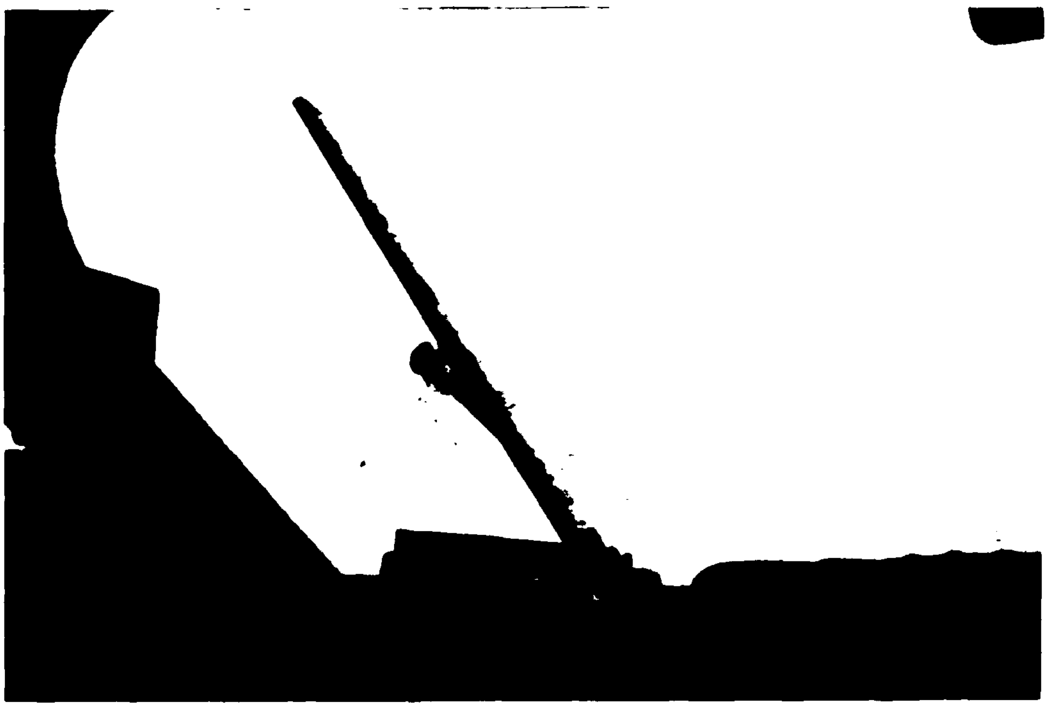


Photo 20. Natural Icing, Phase III, -7.5°C, 0.28 gm/m^3, 33 to 240 micron droplet size. Pilots windshield from cockpit.

Photo 21. Natural Icing, Phase III, -7.5°C, 0.28 gm/m^3, 33 to 240 micron droplet size. Windshield

Photo 22. Natural Icing, Phase III, -9°C, 0.35 gm/m^3, dent in left drop tank

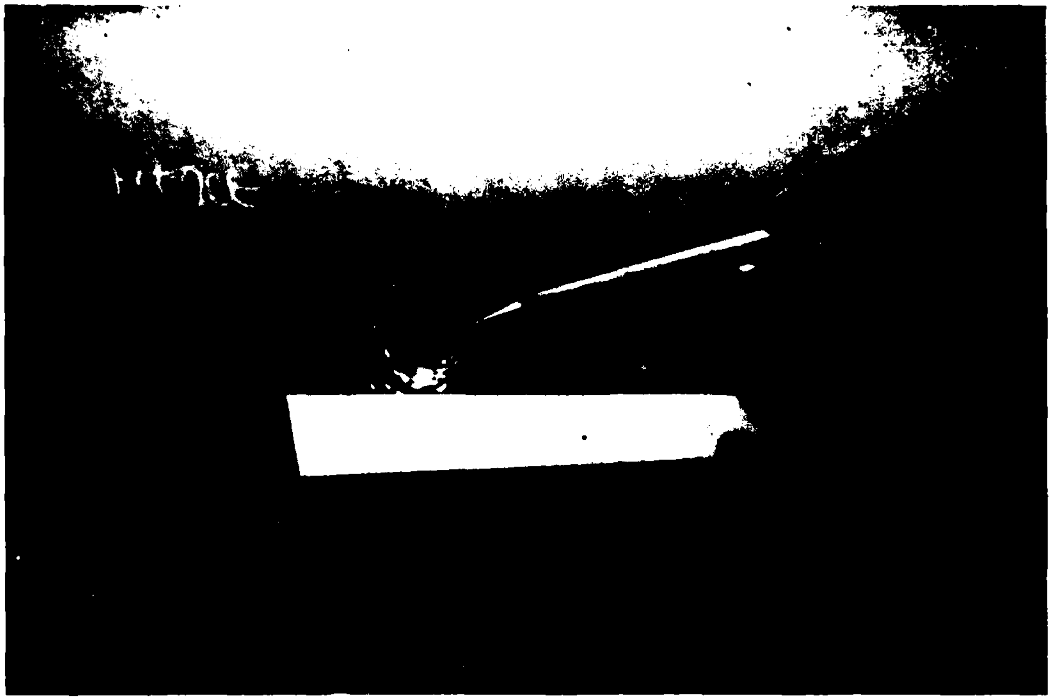


Photo 23. Natural Icing, Phase III, -9°C, 0.35 gm/m^3, dent in right drop tank

Photo 24. Natural Icing, Phase III, -9°C, 0.35 gm/m^3, dent in left vertical tail

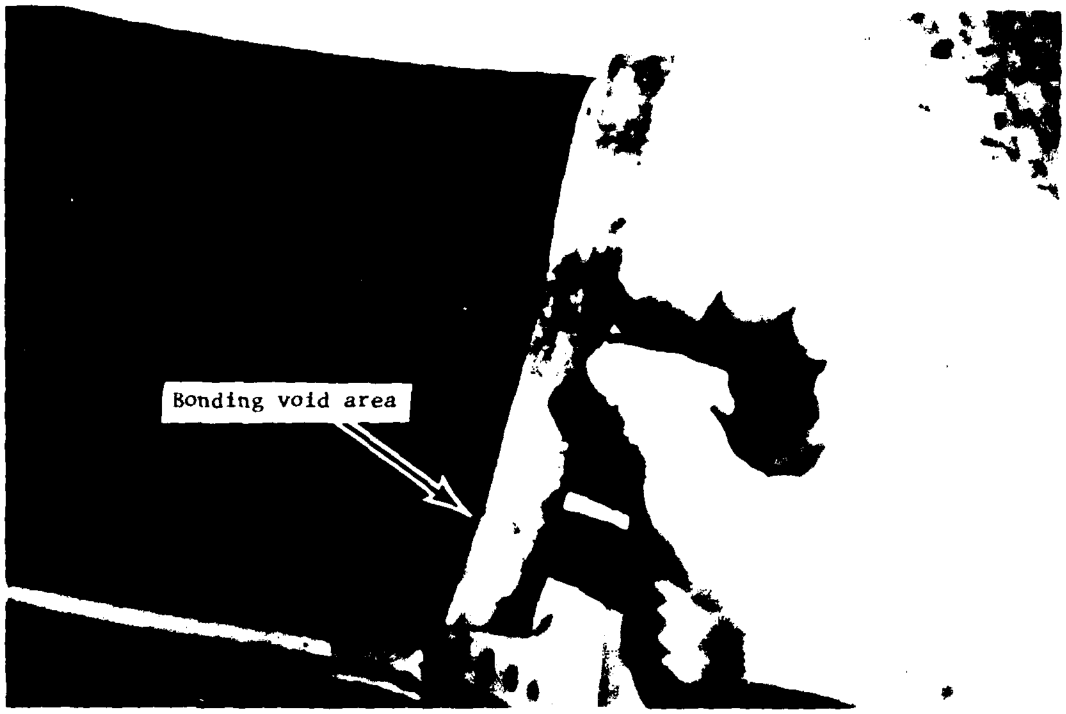


Photo 25. Natural Icing, Phase III, Bonding void in removable cowl half

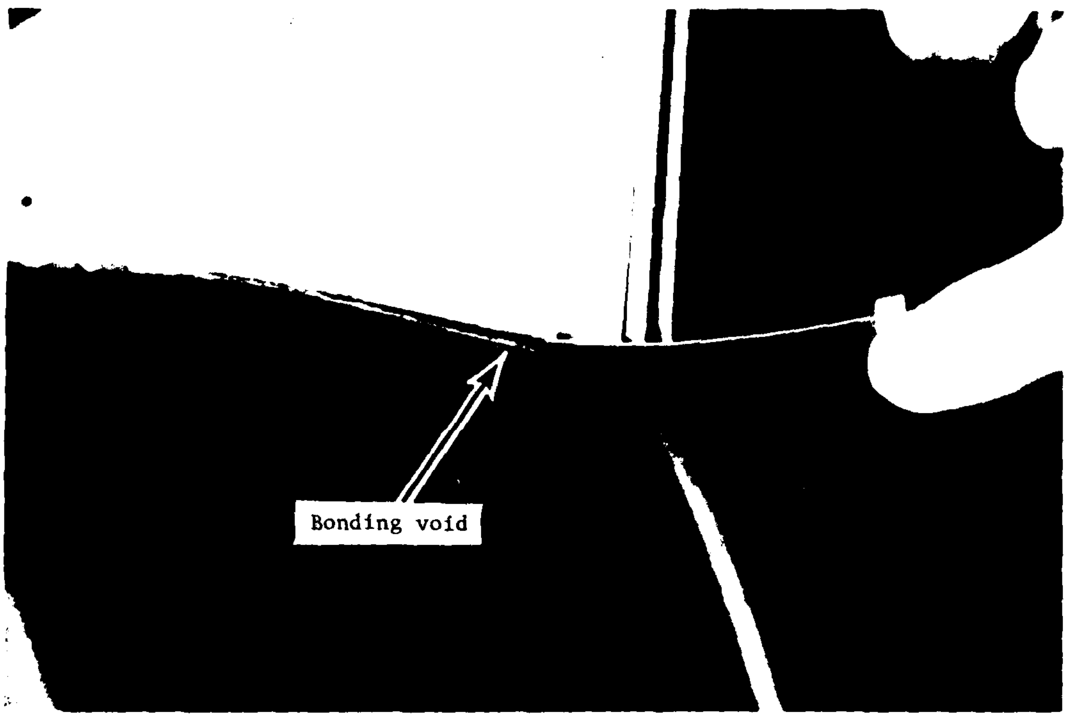


Photo 26. Natural Icing, Phase III, Bonding void in removable cowl half

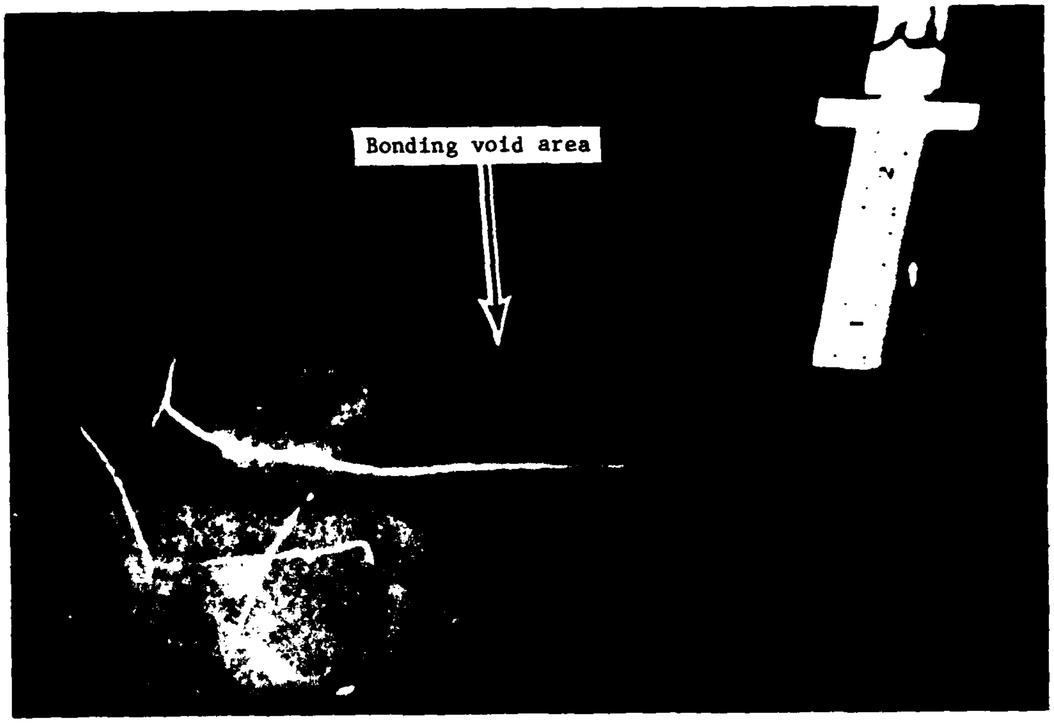


Photo 27. Natural Icing, Phase III, Bonding void in removable cowl half-cowling exterior

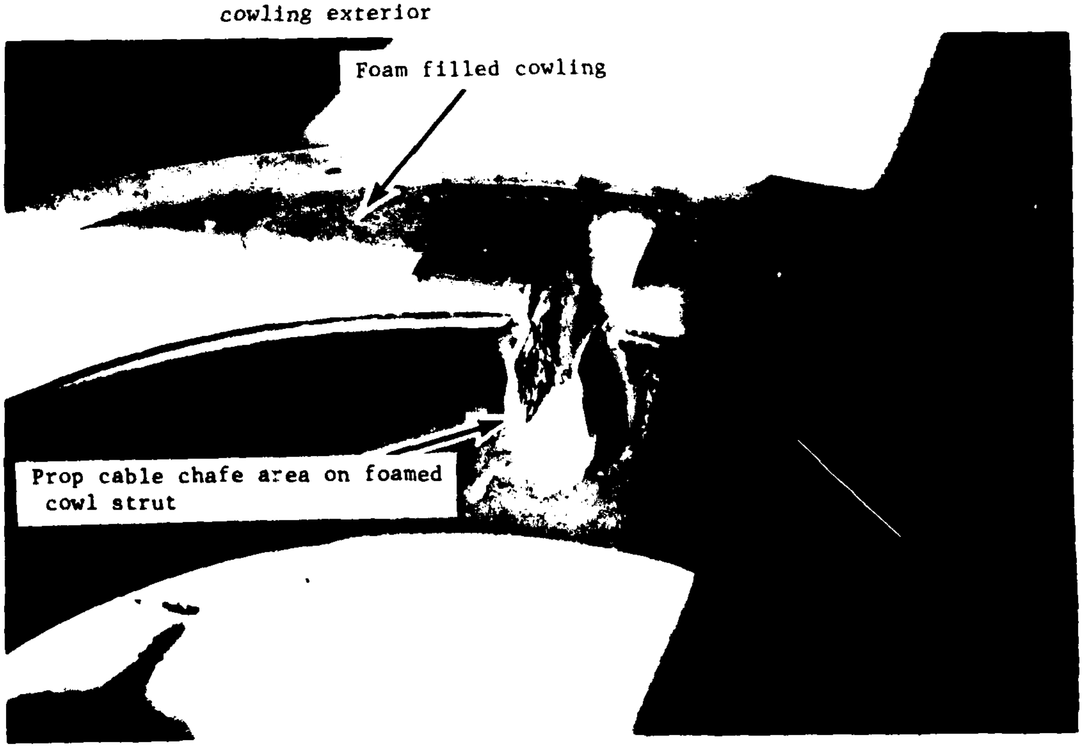


Photo 28. Natural Icing, Phase III, Foamed, removable cowl half

APPENDIX G. EQUIPMENT PERFORMANCE REPORTS

The enclosed Equipment Performance Reports (EPRs), DARCOM Form 2134, 1 September 1976, were submitted by AVNDTA during the Phase III natural icing evaluation.

EQUIPMENT PERFORMANCE REPORT
(DARCOM AMCR 700-38)

DATE: 19 April 1982

OFFICE SYMBOL: STEBG-ST-P

TO	FROM:
USE LABELS	Commander US Army Aviation Development Test Activity Fort Rucker, AL 36362

1. EPR NO.:	2. TECOM/AVSCOM PROJ NO.:	3. TEST TITLE
KF-01	4-AI-039-OV1-004	OV-1D Natural Icing Test

I MAJOR ITEM DATA

4. MODEL: JOV-1D	5. SERIAL NO.: 68-15932
6. QUANTITY: 1	7. LIFE PERIOD: 1665.0
8. MFR: Grumman Aircraft Corporation	9. USA NO.: unknown

II PART DATA

10. NOMENCLATURE/DESCRIPTION: Cowl, removable deicer ring

11. FSN: N/A	12. MFR PART NO.: 134P83100-3
13. DRAWING NO.: N/A	14. MFR: Grumman Aircraft Corporation
15. QUANTITY: 1	16. NEXT ASSEMBLY: ring cowl
17. MAC FUNCTIONAL GRP: 0212	18. PART TEST LIFE: 1665.0

III INCIDENT DATA

19. DATE OF OCCURRENCE: 17 April 1982	20. TYPE OF REPORT:	21. ACTION TAKEN:
22. MAINT SPT, ELM, CODE: RAM	X a. INCIDENT	a. REPLACED
	b. INFORMATION	X b. REPAIRED

23. OBSERVED DURING:	24. TEST ENVIRONMENT:	25. INCIDENT CLASSIFICATION:	
a. OPERATION	Natural icing flight test		c. ADJUSTED
b. MAINTENANCE		a. CRITICAL	d. DISCONNECTED
X c. INSPECTION		X b. MAJOR	e. REMOVED
d. OTHER		c. MINOR	f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22):

a. During the post flight inspection following the second natural icing flight of the day at Salem, Oregon, two bonding separations were noted on the removable deicer ring cowl for engine number 1. There ~~were~~ was no blistering, just failure of the bonding material.

b. The first separation was centered at 11 o'clock position on the external portion of the ring cowl along the trailing edge of the heated ring cowl cap which contains the deicing heating element. The separation measured approximately 5 3/4" long with a measurement depth of 3/4".

c. The second separation was located at the 9 o'clock position (internal portion) along the bottom edge of the removable cowl projecting forward to a depth of 4 1/4" and a measurement width of 1 7/8".

d. This EPR has been classified as a major incident because it did ground the aircraft until the internal surface separation could be repaired.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: N/A

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
EDWARD A. GILMORE, JR., CW4, AV AUTOVON: 558-6202/2490	JOHN O. TURNAGE, LTC(P), INF Deputy Commander for Test

DARCOM FORM 1 SEP 76 2134 — *Previous edition may be used until exhausted.*

EQUIPMENT PERFORMANCE REPORT (DARCOM AMCR 700-38)	DATE: 20 April 1982
	OFFICE SYMBOL: STEBG-ST-P

TO:	FROM:
USE LABELS	Commander US Army Aviation Development Test Activity Fort Rucker, AL 36362

1. EPR NO.:	2. TECOM/AVSCOM PROJ NO.:	3. TEST TITLE
KF-2	4-AI-039-0V1-004	OV-1D Natural Icing Test

I MAJOR ITEM DATA

4. MODEL: JOV-1D	5. SERIAL NO.: 68-15932
6. QUANTITY: 1	7. LIFE PERIOD: 1665.0
8. MFR: Grumman Aircraft Corporation	9. USA NO.: unknown

II PART DATA

10. NOMENCLATURE/DESCRIPTION: Cowl stationary deicing ring

11. FSN: 1560-00-176-2908	12. MFR PART NO.: 134P 80100-3
13. DRAWING NO.: N/A	14. MFR: Grumman Aircraft Corporation
15. QUANTITY: 1	16. NEXT ASSEMBLY: ring cowl assembly
17. MAC FUNCTIONAL GRP: 12	18. PART TEST LIFE: 1665.0

III INCIDENT DATA

19. DATE OF OCCURRENCE: 17 April 1982
22. MAINT SPT, ELM, CODE: RAM

23. OBSERVED DURING:		24. TEST ENVIRONMENT:	20. TYPE OF REPORT:		21. ACTION TAKEN:	
	a. OPERATION	Natural icing flight test	X	a. INCIDENT		a. REPLACED
	b. MAINTENANCE			b. INFORMATION		b. REPAIRED
X	c. INSPECTION		25. INCIDENT CLASSIFICATION:			c. ADJUSTED
	d. OTHER			a. CRITICAL		d. DISCONNECTED
				b. MAJOR		e. REMOVED
			X	c. MINOR	X	f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22):

a. During post flight inspection following second natural icing flight of the day at Salem, Oregon, an open circuit was discovered on B_1 deicing element circuit of stationary ring cowl of engine #1. Connector pins at E-M have allowable resistance range of 9.59 - 10.61 ohms. The open circuit caused the ohm value to increase to 13.1 ohms.

b. A second continuity check was completed on Monday, 19 April 1982, and the circuit was still open. It was thought that moisture had caused these problems, but had not. A consultation was held with Mr. J. Delporte (Grumman Aerospace Corp) and he advised that B_1 circuit had 4 legs. The opening of 1 leg would allow the resistance to increase to 13.1 ohms. He felt the loss of 1 leg was not significantly detrimental and the natural icing test should continue.

c. This is a minor incident in that a malfunction which is not repetitive nor of generic nature of the test materiel occurred.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: N/A

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
EDWARD A. GILMORE, JR., CW4, AV AV: 558-6202/2490	JOHN D. TURNAGE, LTC(P), INF Deputy Commander for Test

DARCOM FORM 1 SEP 76 2134 — *Previous edition may be used until exhausted.*

EQUIPME . PERFORMANCE REPORT
(DARCOM AMCR 700-38)

DATE: 4 May 1982
OFFICE SYMBOL: STEBG-ST-P

TO: USE LABELS

FROM: Commander
US Army Aviation Development Test Activit
Fort Rucker, AL 36362

1. EPR NO.:	2. TECOM/AVSCOM PROJ NO.:	3. TEST TITLE
KF-03	4-AI-039-OV1-004	OV-1D Natural Icing Test

I MAJOR ITEM DATA

4. MODEL: JOV-1D	5. SERIAL NO.: 68-15932
6. QUANTITY: 1	7. LIFE PERIOD: 1672.4
8. MFR: Grumman	9. USA NO.: Unknown

II PART DATA

10. NOMENCLATURE/DESCRIPTION: Generator, A.C.

11. FSN: N/A	12. MFR PART NO.: 07639-AGE 1XB
13. DRAWING NO.: N/A	14. MFR: Leland
15. QUANTITY: 1	16. NEXT ASSEMBLY: Anti-Ice System
17. MAC FUNCTIONAL GRP: 12	18. PART TEST LIFE: 12.4 Hours

III INCIDENT DATA

19. DATE OF OCCURRENCE: 2 May 1982
22. MAINT SPT, ELM, CODE: RAM

23. OBSERVED DURING:	24. TEST ENVIRONMENT:	20. TYPE OF REPORT:	21. ACTION TAKEN:
X a. OPERATION	During Natural Icing Flight (14,676 ft density altitude)	X a. INCIDENT	a. REPLACED
b. MAINTENANCE		b. INFORMATION	b. REPAIRED
c. INSPECTION		25. INCIDENT CLASSIFICATION:	c. ADJUSTED
d. OTHER		a. CRITICAL	d. DISCONNECTED
		X b. MAJOR	X e. REMOVED
		c. MINOR	f. NONE

IV INCIDENT DESCRIPTION

26. DESCRIBE INCIDENT FULLY (INCLUDE IMPACT OF INCIDENT ON MAC CODE IDENTIFIED IN BLOCK 22):

a. On 2 May 1982, during natural icing flight test, approximately 60 NM WNW of Salem, Oregon, at 14,600 feet altitude (DA 14,676) the #2 engine anti-ice system caution light illuminated indicating the system was inoperative. The system had been operating for 42 minutes. The anti-ice system was kept on for an additional 2 minutes while a descent was initiated to leave the icing conditions. The system was turned off when the aircraft cleared icing conditions. The aircraft reencountered natural icing, the anti-icing system was turned on, and the #2 system caution light remained out for approximately 45 seconds prior to illuminating (a second time). The off time had been approximately 1 minute. When the aircraft cleared the natural ice exposure, the system was secured.

b. After landing, the aircraft engines were secured and a hot electrical odor was noticed by the ground crew as they approached the aircraft. A visual inspection of the generator indicated the generator case temperature had risen to 250°F (measured by a temperature template fixed to generator case), but no other indication of fire or overheating was found. The engine compartment fire warning light, located in the aircraft cockpit, did not illuminate during the flight.

INCIDENT CLASSIFICATION IS SUBJECT TO RECLASSIFICATION

27. DEFECTIVE MATERIAL SENT TO: Grumman

28. NAME, TITLE & TEL EXT OF PREPARER:	29. FOR THE COMMANDER:
EDWARD A. GILMORE, CW4, AVN, Test Project Manager, AV: 558-6202/3013	JOHN O. TURNAGE, LTC(P), INF Deputy Commander for Test

DARCOM FORM 1 SEP 76 2134 — *Previous edition may be used until exhausted.*

Block #26 (cont)

c. A continuity check was conducted and internal generator damage was indicated.

d. Mr. R. Robbins (USAAEFA), Project Officer, contacted Mr. J. Delaporte (Grumman Aircraft Corporation), as to the generator disposition. It was determined that the generator should be removed from the aircraft engine and a pad cover placed on the Western Gear Box. The subject generator will be boxed and returned, with test aircraft, to the Grumman facility via Ft Rucker, Alabama.

e. This EPR has been classified as a Major incident because it rendered the test item inoperative until repairs can be accomplished. The termination of testing is due to loss of weather conditions which is coincidental to failure of the test item.

Appendix H. Report, Limited Artificial Icing Tests of the OV-1D Project No. 80-16

DEPARTMENT OF THE ARMY

U. S. ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

JUL 9 1981

DAVTE-TB

SUBJECT: Letter Report, *Limited Artificial Icing Tests of the OV-1D*, USAAEFA Project No. 80-16

Commander
US Army Aviation Research and
Development Command
ATTN: DRDAV-DI
4300 Goodfellow Blvd.
St. Louis, Missouri 63120

1. REFERENCES. a. Letter, AVRADCOM, DRDAV-DI, 5 November 1980, subject: Limited Artificial Icing Tests of the OV-1D.

b. Technical Manual, TM 55-1510-213-10, *Operator's Manual OV-1D/RV-1D Aircraft*, 4 August 1978 with Changes 1 and 2.

c. Technical Manual, TM 55-1510-213-23-3, *Aviation Unit and Intermediate Unit Maintenance Manual, Army Models OV-1D/RV-1D Aircraft*, 31 October 1978 with Changes 1 and 2.

d. Technical Manual, TM 11-5895-1051-12, *Operator's and Organizational Maintenance Manual, Aviation Unit Maintenance AN/ALQ-147A(V)1 and (V)2*, October 1979.

e. Letter, DRDAV-DI, 5 December 1980, subject: Airworthiness Release for OV-1D S/N 68-15932 for USAAEFA, Project No. 80-16, Limited Icing Tests of the OV-1D.

f. Letter, USAAEFA, Project No. 80-16, 21 November 1980, *Abbreviated Test Plan, Limited Artificial Icing Tests of the OV-1D*.

2. BACKGROUND. The US Army Aviation Research and Development Command (AVRADCOM) tasked the US Army Aviation Engineering Flight Activity (USAAEFA) (ref 1a) to conduct a limited artificial icing evaluation on the OV-1D. Operational experience in Europe has indicated that during flight in icing conditions, ice accretes on the engine nose cowling assembly. It is suspected that accreted ice may break off the engine

nose cowling and be ingested into the engine, causing possible engine damage or failure. Additionally, no ice accretion information exists relative to the louvered, scarfed shroud suppressor (LSSS) or the operation of the infrared countermeasures (IRCM) pod AN/ALQ-147A(V)1 in icing conditions.

3. TEST OBJECTIVES. The objectives of this test were to conduct limited artificial and natural icing flights on the OV-1D aircraft to:
a. Determine the ice accretion characteristics of the engine nose cowling assembly, propeller, and propeller spinner, and determine if accreted ice is subject to being ingested into the engine.

b. Determine the ice accretion characteristics of the LSSS inlet scoop.

c. Evaluate the effect of ice accummulation on the operation of the AN/ALQ-147A(V)1.

4. DESCRIPTION. The test aircraft was a standard OV-1D serial number 68-15932 configured with the LSSS engine inlet scoop, AN/ALQ-147A(V)1 on wing station 6 and 150-gallon Sergeant Fletcher fuel tanks on stations 3 and 4 (photo 1, incl 1). Externally mounted test equipment consisted of a nonaspriated Rosemount ice detector mounted on a boom on wing station 5 and an airfoil shaped visual ice accretion probe mounted on the copilot's entrance hatch (photo 1, incl 1). The engine inlet anti-ice system consists of engine bleed air and hot engine oil heated inlet struts and bleed air heated inlet guide vanes. The engine nose cowl assembly consisting of the cowling ring and struts, and the engine oil cooler inlet and splitter have both an anti-ice and deice system incorporating heating elements powered by 115 volts alternating current. The leading edge of the nose cowl assembly is anti-iced with continuously heated elements when the system is turned on. The remaining heating elements in the nose cowl assembly and also heating elements in the propeller and propeller spinner are sequentially heated in a predetermined sequence established by a timer. A schematic of the heating elements in the engine nose cowl assembly, propeller, and propeller spinner is shown in figure 1, inclosure 2. A detailed description of the OV-1D and the propeller and cowl deicing systems is contained in the operator's manual (ref 1b) and the aviation unit and intermediate unit maintenance manual (ref 1c). The LSSS engine inlet scoop is an integral part of the engine cowling and is located on top of the engine upper cowling. Ambient ram air enters the LSSS inlet and diffuses the engine exhaust gases. The inlet scoop has no anti-ice or deice protection. The AN/ALQ-147A(V)1 is a self contained IRCM pod mounted on wing station 6. The air inlet, located below the main body, has no anti-ice or deice protection. A detailed description of the AN/ALQ-147A(V)1 is contained in the operator's and organizational maintenance manual (ref 1d).

DAVTE-TB
SUBJECT: Letter Report, Limited Artificial Icing Tests of the OV-1D, USAAEFA Project No. 80-16

5. TEST SCOPE. Limited artificial and natural icing tests were conducted in the St. Paul, Minnesota, area from 8 through 22 December 1980. A total of 12 test flights were conducted totaling 12.5 hours. Of these flights, 11 were conducted in the artificial icing environment and one flight was conducted in the natural icing environment. A total of 5.6 and 0.2 hours productive flight time, were accumulated in artificial and natural icing, respectively. Operating limitations contained in the operator's manual (ref 1b) and the airworthiness release (ref 1e) were observed. The tests were conducted at an average gross weight of 14,800 pounds with a mid center of gravity (ref 1f). Test pressure altitude ranged from 2500 to 7500 feet. Test airspeed was 120 knots true airspeed (KTAS) in the artificial icing environment and 205 KTAS in the natural icing environment with a propeller speed of 1450 rpm. Flights in the artificial icing environment were conducted at ambient temperatures and liquid water contents which approximate natural icing conditions of moderate intensity as shown in table 1.

6. TEST METHODOLOGY. Artificial icing of the OV-1D was conducted by flying the test aircraft in a spray cloud generated by the CH47C helicopter icing spray system (HISS). All artificial icing flights were performed at a predetermined liquid water content (LWC) and outside air temperature (OAT). Water flow rate from the HISS was used to establish the desired LWC for each artificial icing flight. Prior to entering the artificial icing cloud the test aircraft's pitot heat, propeller and cowling deice systems and the engine bleed air operated windshield defog system were turned ON. Anti-ice and deice systems were operated continuously while in the icing environment with the exception of the wing and tail deice boots and windshield anti-ice, which were activated as required. The test aircraft was flown at 120 KTAS and 150 feet standoff distance behind the HISS with the right half of the aircraft immersed in the icing cloud. The aircraft was configured with the landing gear, flaps, and speed brakes retracted and was flown in the cloud for 30 minutes at each predetermined LWC and OAT. Photographic documentation was taken from the test aircraft, HISS, and chase aircraft while in the cloud and after exiting the cloud. The visual ice accretion probe was used to assist in determining ice build-up while in the cloud. The Rosemount ice detector, used in an attempt to determine the LWC of the icing cloud, was unreliable. Operational status of the AN/ALQ-147A(V)1 was monitored by the system cockpit status indicator during flight. The pod-mounted built-in-test-equipment (BITE) was used after landing to evaluate AN/ALQ-147A(V)1 failures. Natural icing tests were conducted by flying the test aircraft into known icing conditions at a cruise speed of 205 KTAS. Photographic documentation was recorded from the test aircraft.

7. RESULTS AND DISCUSSION. a. General. Artificial and natural icing tests of the OV-1D engine nose cowling assembly, propeller, and propeller spinner; LSSS; and AN/ALQ-147A(V)1 were conducted with photographic documentation to substantiate qualitative data. Two deficiencies and two shortcomings were noted as a result of the icing encounters. The unsatisfactory

ice accretion characteristics of the engine nose cowling, propeller, and propeller spinner and the failure of the windshield ice protection system to clear the windshield sufficiently to provide adequate forward visibility after encountering icing conditions are deficiencies. The lack of an adequate engine nose cowling, propeller, and propeller spinner ice protection system status indicator, and malfunction of the AN/ALQ-147A(V)1 due to ice accummulation in the inlet are shortcomings. The ice accretion characteristics of the LSSS inlet scoop are satisfactory. A more detailed report on the operation of the AN/ALQ-147A(V)1 and the LSSS inlet scoop will be published by the US Army Aviation Development Test Activity, Fort Rucker, Alabama.

b. Engine Nose Cowling Assembly, Propeller, and Propeller Spinner Evaluation. (1) The ice accretion characteristics of the engine nose cowling assembly, propeller, and propeller spinner were evaluated in moderate icing conditions behind the HISS at 120 KTAS. Ice buildups were observed on heated surfaces inside the engine nose cowling assembly air inlet, on the propeller spinner, and on the propeller heaters during all test conditions. The artificial icing flights indicated that ice began to accrete both inside and outside the engine air inlet along the 10 and 4 o'clock joints between the fixed and removable nose cowl assemblies as soon as the icing cloud was entered. After 30 minutes immersion in the cloud, ice accretions at the cowling joints were approximately 1-1/2 inches wide and varied in thickness from 3/8 inches at 0.25 gm/m^3 LWC to 1-3/4 inches at 1.0 gm/m^3 LWC. A typical ice accummulation on the 4 o'clock cowling joint at -10°C and 0.75 gm/m^3 LWC is depicted in photograph 2 (incl 1). Ice accretions were also observed during flight on the heated portions of the three nose cowling struts and inner walls of the engine cowling inlet. The ice accretions were evident at all temperatures tested with the largest accretions at colder ambient temperatures or higher LWC's. A typical ice buildup inside the engine cowling inlet and on the 8 o'clock cowling strut at -15°C and 0.5 gm/m^3 LWC is shown in photograph 3, inclosure 1. Ice accummulations at -20°C and 0.5 LWC (photo 4, incl 1) revealed ice inside the inlet at the 1 to 2 o'clock and 7 to 9 o'clock positions, on the cowling struts, and cowling half joints.

(2) Four first stage compressor turbine blades were damaged during the 30-minute icing encounter at -20°C and 0.5 gm/m^3 LWC. One damaged second stage compressor turbine blade was found during engine teardown at the completion of the test. All five of the blades were burnished and rendered serviceable Three inlet guide vanes behind the 4 o'clock cowling strut were bent and one first stage compressor turbine blade was damaged beyond repair (photo 5, incl 1) during the flight at -10°C and 0.75 gm/m^3 LWC. Although the OV-1 was not flown for more than 30 minutes, in icing conditions of less than moderate severity, flight in trace or light icing conditions with ambient temperatures below -5°C and immersion times typical for mission profiles (3.0 hours) may also cause ice buildups

which could result in engine damage.

(3) The end of the propeller spinner accreted a one-to-two-inch thick donut shaped ice formation which extended aft along the spinner. This ice donut often fell from the spinner prior to landing at the warmer test temperatures; however, it is not known if this ice was ingested through the inlet. Splinter shaped ice accretions on the spinner became more apparent at the colder temperatures. Typical spinner ice accretions at -15°C and -20°C with 0.5 gm/m^3 LWC are shown in photographs 6 and 7, inclosure 1, respectively.

(4) Ice accummulated on the propeller blade heaters on all icing flights. The side of the fuselage and right external fuel tank were dented by ice being thrown from the propeller (photo 6, incl 1). Asymmetric propeller ice sheds induced high frequency airframe vibrations which often lasted 3 to 5 minutes. Typical propeller ice accretions at -15°C and -20°C with 0.5 gm/m^3 LWC are depicted in photographs 8 and 9, inclosure 1, respectively.

(5) Natural and artificial ice accretion characteristics were essentially the same. The natural icing encounter occurred at -6°C and 205 KTAS. Ten minutes were flown in the natural ice environment resulting in a 0.5-inch accummulation. Ice accretions on the nose of the propeller spinner and on the 4 o'clock joint between the fixed and removable nose cowling assembly halves were observed from the cockpit and were similar to ice accreted behind the HISS at the same temperature.

(6) Throughout the tests, the engine nose cowling assembly, propeller, and propeller spinner ice protection systems did not prevent ice accretions. The airframe and external fuel tank were damaged, high frequency airframe vibrations occurred from propeller ice shedding, and engine inlet guide vanes and compressor blades were damaged due to ice ingestion. The ice accretion characteristics of the engine nose cowling, propeller, and propeller spinner can result in engine damage and are a deficiency.

c. Windshield Ice Protection System. The engine bleed air operated windshield defog and the windshield alcohol anti-icing systems were turned on prior to entering the natural and artificial icing conditions. Although the systems were operating, the forward visibility through the pilot's and copilot's windshield was distorted and severely reduced. Landing under these conditions will significantly increase the pilot's workload in an existing high workload situation and could be critical. Failure of the windshield ice protection system to clear the windshield sufficiently to provide adequate forward visibility after encountering icing conditions is a deficiency.

d. Engine Nose Cowling Assembly, Propeller, and Propeller Spinner Ice Protection System Status Indicator. The OV-1 does not have a cockpit status indicator which enables the pilot to determine if the heating elements in the engine nose cowling assembly, propeller, and propeller spinner are functioning properly when the engine deice system is in use. Failure of the No. 1 or No. 2 anti-ice generator may be detected by illumination of the "#1 or #2 ANTI-ICE GEN" caution lights; however, if the anti-ice generator is operating, failure of other elements in the deice system would not be displayed in the cockpit. As a result a pilot could enter icing conditions assumming the aircraft's ice protection system is operable and very quickly accrete engine inlet ice possibly causing engine damage. The lack of an adequate engine nose cowling, propeller, and propeller spinner ice protection system status indicator is a shortcoming.

e. IRCM Pod AN/ALQ-147A(V)1. Due to insufficient inlet air flow at 120 KTAS behind the HISS, the AN/ALQ-147A(V)1 was evaluated at higher airspeeds after exiting the icing cloud. On two separate icing flights at -10°C and 0.75 gm/m^3 LWC the AN/ALQ-147A(V)1 failed to operate at an airspeed of 135-150 knots indicated airspeed (KIAS). The "AIR" status indicator on the systems BITE unit was observed tripped after landing. Ice had accummulated on the air door jack screw inside the air inlet. This ice buildup apparently restricted the air door movement thus preventing proper air modulation for combustion. Failure of the AN/ALQ-147A (V)1 to operate due to ice accummulation in the inlet is a shortcoming.

f. LSSS Inlet Scoop. The LSSS inlet scoop accreted ice on the inlet leading edge with a thin accummulation approximately 1/8-inch thick extending 12 inches into the throat of the inlet. Typical ice accretion on the LSSS at -20°C and 0.5 gm/m^3 is shown in photograph 10, inclosure 1. The ice accumulated on these surfaces was insignificant and appears would not degrade the inlet scoop's effectiveness. The ice accretion characteristics of the LSSS inlet scoop are satisfactory.

8. CONCLUSIONS. a. General. The following conclusions were reached upon completion of the limited artificial icing tests of the OV-1D.

b. Specific. Ice accretion characteristics of the LSSS inlet scoop are satisfactory (para 7f).

c. Deficiencies. (1) Ice accretion characteristics of the engine nose cowling, propeller, and propeller spinner can result in engine damage (para 7b(6)).

(2) Failure of the windshield ice protection system to clear the windshield sufficiently to provide adequate forward visibility after encountering icing conditions (para 7c).

d. Shortcomings. (1) Lack of an adequate engine nose cowling, propeller, and propeller spinner ice protection system status indicator (para 7d).

DAVTE-TB
SUBJECT: Letter Report, Limited Artificial Icing Tests of the OV-1D, USAAEFA Project No. 80-16

(2) Failure of the AN/ALQ-147A(V)1 to operate due to ice accummulation in the inlet (para 7e).

9. RECOMMENDATIONS. a. The OV-1 should be restricted from flight into forecast icing conditions with ambient temperature below -5°C until the deficiencies are corrected.

b. The shortcomings should be corrected prior to operating the OV-1 and AN/ALQ-147A(V)1 in icing conditions.

c. The following restriction should be placed in the operator's manual until the engine and windshield ice protection systems are improved:

> The OV-1 is restricted from flight into forecast icing conditions with ambient temperatures below -5°C.

10. AUTHORS. This report was prepared by CPT Robert D. Robbins, Project Officer/Project Pilot, and CW4 Edward A. Gilmore, Jr. Project Pilot.

Lewis J. McConnell

1 Incl
as

LEWIS J. McCONNELL
Colonel, TC
Commanding

Photo 1. OV-1D Test Aircraft Configuration

Photo 2. Ice on 4 o'clock Cowling Joint

Photo 3. Ice Inside Engine Cowling Inlet
and on 8 o'clock Cowling Strut

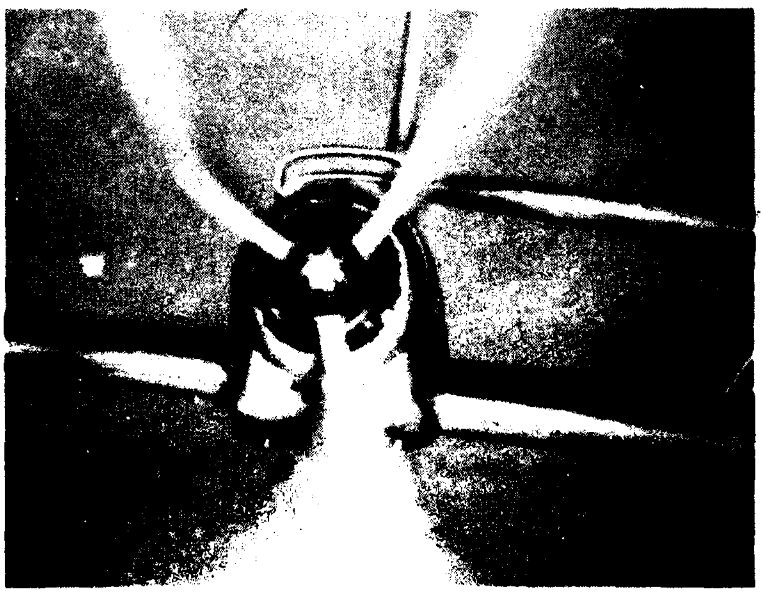


Photo 4. Ice Inside Engine Cowling Inlet at the 1 to 2 o'clock
and 7 to 9 o'clock Positions

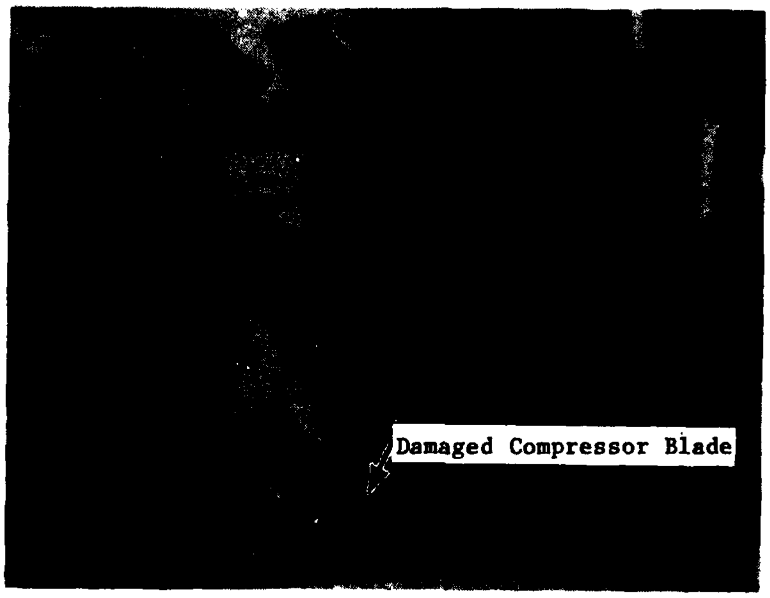


Photo 5. Damaged First Stage Turbine Compressor Blade

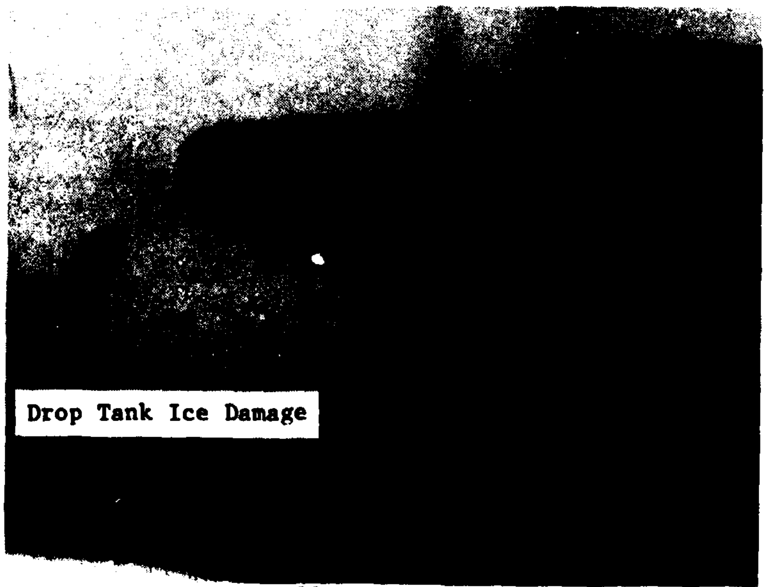


Photo 6. Propeller Spinner Ice Accretions

Photo 7. Propeller Spinner Ice Accretions

Photo 8. Propeller Ice Accretions

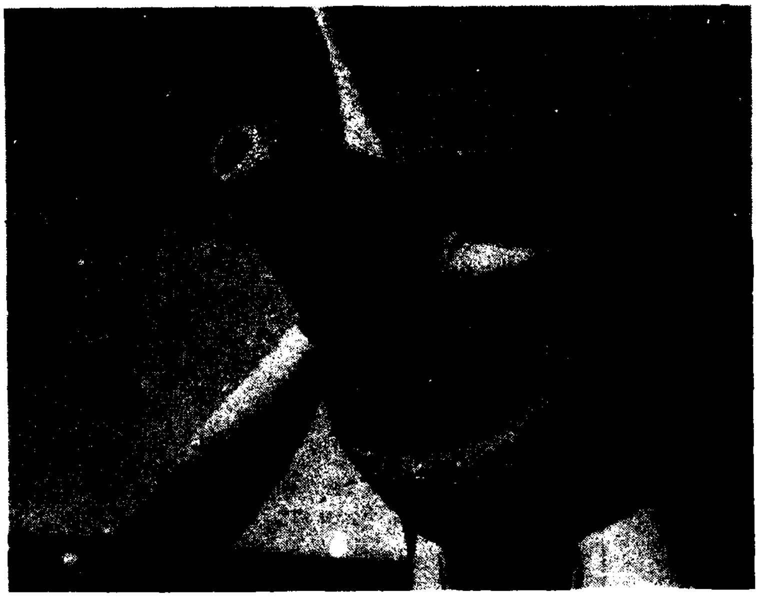


Photo 9. Propeller Ice Accretions

Photo 10. Typical Ice Accretions on LSSS Inlet

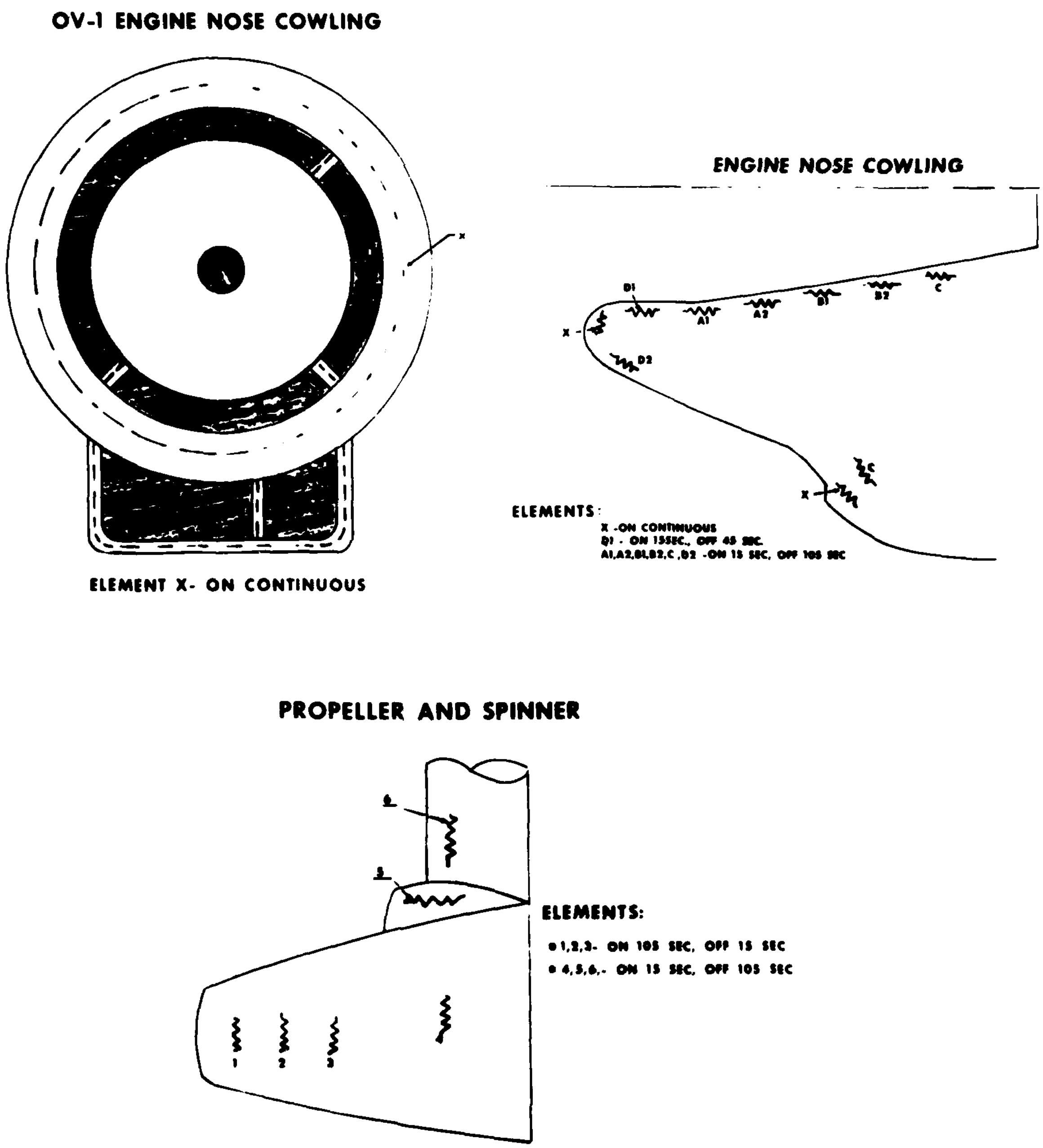


Figure 1. OV-1 Engine Nose Cowling, Propeller, and Spinner Schematics

Table 1. Artificial Icing Test Points

AMBIENT TEMPERATURE (Degrees Centigrade- °C)	LIQUID WATER CONTENT- LWC (grams/meter^3- gm/m^3)			
	0.25	0.5	0.75	1.0
−5		x	x	x
−10		x	x	
−15	x	x		
−20	x	x		

DISTRIBUTION

Deputy Chief of Staff for Logistics (DALO-SMM, DALO-AV)	1
Deputy Chief of Staff Operations (DAMO-RO)	1
Deputy Chief of Staff for Personnel (DAPE-HRS)	1
Deputy Chief of Staff for Research Development and Acquisition (DAMA-PPM-T, DAMA-RA, DAMA-WSA)	3
Comptroller of the Army (DACA-EA)	1
US Army Materiel Development and Readiness Command (DRCDE-SA, DRCQA-E, DRCDE-I, DRCDE-P)	4
US Army Training and Doctrine Command (ATTG-U, ATCD-T, ATCD-ET, ATCD-B)	4
US Army Aviation Research and Development Command (DRDAV-DI, DRDAV-EE, DRDAV-EG)	10
US Army Test and Evaluation Command (DRSTE-CT-A, DRSTE-TO-O)	2
US Army Troop Support and Aviation Materiel Readiness Command (DRSTS-Q)	1
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (DRXSY-R, DRXSY-MP)	1
US Army Operational Test and Evaluation Agency (CSTE-POD)	1
US Army Armor Center (ATZK-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-TSM-U)	4
US Army Combined Arms Center (ATZLCA-DM)	1
US Army Safety Center (IGAR-TA, IGAR-Library)	2

US Army Research and Technology Laboratories/Aeromechanics Laboratory (DAVDL-AL-D)	1
Defense Technical Information Center (DDR)	12
US Military Academy (MADN-F)	1
US Army Research and Technology Laboratories/Applied Technology Laboratory (DAVDL-ATL-D, DAVDL-Library)	2
US Army Research and Technology Laboratories/Proplusion Laboratory (DAVDL-PL-D)	1
US Army Research and Technology Laboratories (DAVDL-AS, DAVDL-POM (Library))	2
MTMC-TEA (MTT-TRC)	1
ASD/AFXT	1
Special Electronic Mission Aircraft (DRCPM-AE-T)	2
DCASPRO-Grumman (H. Hoffman)	2
US Army Troop Support and Aviation Readiness Command (DRSTS-M)	1

DATE
FILMED

5-8